

2002

Antipredator conditioning in Mississippi Sandhill Cranes (*Grus canadensis pulla*)

Jennifer Jill Heatley

Louisiana State University and Agricultural and Mechanical College, jheatley@vetmed.lsu.edu

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_theses



Part of the [Veterinary Medicine Commons](#)

Recommended Citation

Heatley, Jennifer Jill, "Antipredator conditioning in Mississippi Sandhill Cranes (*Grus canadensis pulla*)" (2002). *LSU Master's Theses*. 4127.

https://digitalcommons.lsu.edu/gradschool_theses/4127

This Thesis is brought to you for free and open access by the Graduate School at LSU Digital Commons. It has been accepted for inclusion in LSU Master's Theses by an authorized graduate school editor of LSU Digital Commons. For more information, please contact gradetd@lsu.edu.

ANTIPREDATOR CONDITIONING IN MISSISSIPPI SANDHILL CRANES
(*GRUS CANADENSIS PULLA*)

A Thesis
Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
In partial fulfillment of the
Requirements for the degree of
Master of Science

in

The Interdepartmental Program in Veterinary Medical Sciences

by
Jennifer Jill Heatley
DVM, Texas A&M University, 1995
May 2002

To Rita

ACKNOWLEDGMENTS

I thank Dr. Susan Mikota for her contributions and continued support of this project. I am grateful for the endless cooperation and patience of the staff at the Freeport MacMoran Species Survival Center and the Audubon Institute Center for Research of Endangered Species in New Orleans, Louisiana, especially Barbara Vincent and Jeff Vaccarro. A personal thank you also goes to Dr. Karen Miller for her persistence, wonderful attitude and patience in donating the services of Bob the bobcat. I also extend thanks to Dr. Betsy Dresser, Director of Research at the Audubon Institute Center for Research of Endangered Species, for her support of this project. I am grateful to the entire staff at Mississippi Sandhill Crane National Refuge, especially Scott Hereford for lending his input, expertise and experience in working with the Mississippi Sandhill Crane.

Dr. Tom Tully, Dr. Glenn Olsen and Dr. Giselle Hosgood have been and continue to be inspiring role models and have been supportive mentors for this project. I especially laude Dr. Tom Tully as my residency program mentor and major professor for his efforts to ensure my timely completion of all aspects of my program. I further thank Drs. Olsen and Tully for their encouragement of my presentation of portions of this study both the forums of the Association of Avian Veterinarians Conference and the Annual Whooping Crane Meeting. Dr. Giselle Hosgood was instrumental in initial experimental design and timely completion of this project and for this I am grateful beyond words. Appreciation is extended to all members of the Zoological Medicine Service of the Louisiana State University

School of Veterinary Medicine, but especially Dr. Mark Mitchell, for allowing me to fulfill my residency program responsibilities. I am grateful for all the mentorship and support provided by Dr. Gordon Pirie throughout my internship and residency programs in cooperation with the Baton Rouge Zoo.

I acknowledge and extend appreciation for technical assistance in manuscript preparation to Mr. Michael Broussard and Ms. Cathy Moran and especially Ms. Marinda Sherman for her tireless efforts in reference procurement.

Special thanks are due to Dr. David Senior, Head of the Veterinary Clinical Sciences Department, for his support of the internship and residency programs within the Zoological Medicine Department at Louisiana State University's School of Veterinary Medicine. I sincerely appreciate the daily and sometimes hourly assistance of Ms. Jackie Bourgeois in every aspect of my program at Louisiana State University. There are many people not specifically mentioned here, without whom this project would not have proceeded to completion; I am indebted to them.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	iii
LIST OF TABLES.....	vii
LIST OF FIGURES.....	viii
ABSTRACT.....	ix
INTRODUCTION.....	1
Historical Review of the Status of the Mississippi Sandhill Crane.....	1
Causes of Decline of Wild Mississippi Sandhill Crane Populations.....	3
Previous Reintroduction Programs of North American Cranes.....	5
LITERATURE REVIEW.....	12
Causes of the Decline of Endangered Avian Species.....	12
Captive Breeding Programs of Endangered Avian Species.....	19
Reintroduction Programs of Endangered Avian Species.....	22
Overview of Avian Antipredator Behavior.....	26
Crane Antipredator Behavior Review.....	35
Avian Cognition and Learning Abilities.....	44
Antipredator Conditioning in Avian Reintroduction Programs.....	49
MATERIALS AND METHODS.....	52
Site Description.....	52
Experimental Subjects.....	52
Model Selection.....	55
Identification of Experimental Subjects.....	56
Antipredator Conditioning.....	56
Predator Exposure.....	56
Data Collection.....	57
Release.....	59
Statistical Analysis.....	61
RESULTS.....	63
Release Phase.....	63
Behavioral Phase.....	63
DISCUSSION.....	66
Comparison of Avian Antipredator Conditioning Methods.....	66
Factors Affecting Subadult Mississippi Sandhill Crane Behavior During Antipredator Conditioning.....	67

Other Factors Affecting Mississippi Sandhill Crane Antipredator Behavior.....	69
SUMMARY AND CONCLUSIONS.....	73
Summary.....	73
Conclusions.....	74
REFERENCES.....	75
APPENDIX A. Behavior Logs.....	86
APPENDIX B. Tabulated Behaviors of Subadult Mississippi Sandhill Cranes.....	88
APPENDIX C. Information of Subadult Mississippi Sandhill Cranes of this Study.....	94
APPENDIX D. Crane Behavior Recorded during Antipredator Conditioning Trials of Captive Mississippi Sandhill Cranes.....	95
Video 1. Tall Alert Posture in Subadult Mississippi Sandhill Cranes.....	95
Video 2. Preflight Posture in Subadult Mississippi Sandhill Cranes.....	95
Video 3. Guard Call in Subadult Mississippi Sandhill Cranes.....	95
Video 4. Bill Stab in Subadult Mississippi Sandhill Cranes.....	95
Video 5. Unison Call in Adult Mississippi Sandhill Cranes.....	95
VITA.....	96

LIST OF TABLES

Table 1. Antipredator Behaviors Exhibited by Model Mississippi Sandhill Cranes During Initial Predator Exposure.....	55
Table 2. Crane Behaviors Appropriate in Response to Predators.....	59
Table 3. Summary of the Predator Control Program at the Mississippi Sandhill Crane National Wildlife Refuge.....	61
Table 4. Summary of Data Collected.....	61
Table 5. Frequencies of Appropriate Behaviors of Subadult Mississippi Sandhill Cranes Undergoing Antipredator Conditioning.....	64
Table 6. Direct Observation Data Log.....	86
Table 7. Filmed Observation Data Log.....	87
Table 8. Behaviors of Subadult Mississippi Sandhill Cranes Prior to Exposure to a Coyote.....	88
Table 9. Behaviors of Subadult Mississippi Sandhill Cranes During Exposure to a Coyote.....	89
Table 10. Behaviors of Subadult Mississippi Sandhill Cranes After Exposure to a Coyote.....	90
Table 11. Behaviors of Subadult Mississippi Sandhill Cranes Prior to Exposure to a Bobcat.....	91
Table 12. Behaviors of Subadult Mississippi Sandhill Cranes During Exposure to a Bobcat.....	92
Table 13. Behaviors of Subadult Mississippi Sandhill Cranes After Exposure to a Bobcat.....	93
Table 14. Signalment, Release, and Mortality Data of Mississippi Sandhill Cranes of this Study.....	94

LIST OF FIGURES

Figure 1. Site Description for Antipredator Conditioning of Subadult Mississippi Sandhill Cranes in Year 1.....	53
Figure 2. Site Description for Antipredator Conditioning of Subadult Mississippi Sandhill Cranes in Year 2.....	54
Figure 3a. Bobcat (<i>Lynx rufus</i>) Used for Antipredator Conditioning of Subadult Mississippi Sandhill Cranes.....	58
Figure 3b. Coyote (<i>Canis latrans</i>) Used for Antipredator Conditioning of Subadult Mississippi Sandhill Cranes.....	58
Figure 4. Subadult Mississippi Sandhill Crane Release Sites.....	60

ABSTRACT

The Mississippi Sandhill Crane (*Grus canadensis pulla*), the most endangered North American crane, is considered critically endangered and is protected by Federal and State law. Substantial funding has established the Mississippi Sandhill Crane National Wildlife Refuge in Southern Mississippi and an artificial insemination / breeding facility at the Audubon Center for Research of Endangered Species in New Orleans, Louisiana to promote species recovery. In spite of extensive time, labor, and money invested in captive propagation, juvenile Mississippi Sandhill Cranes suffer substantial mortality due to predation by bobcats (*Lynx rufus*), coyotes (*Canis latrans*) and red tailed hawks (*Buteo jamaicensis*) upon reintroduction to the refuge. Studies have shown decreased avian mortality in reintroduction programs incorporating antipredator conditioning. Appropriate antipredator behaviors are likely innate in cranes, however the object at which to direct these behaviors may require social learning in lieu of the normally long period of parental care known in this species. An antipredator conditioning program was conducted prior to release for 2 years in juvenile Mississippi Sandhill Cranes using live tame predators and conspecific presence to teach predator recognition and appropriate responses. Death of juvenile cranes upon reintroduction to the refuge due to predation has not occurred since the inception of the program. However, factors such as an increase in predator control or differing weather conditions may have contributed to these results. Behavioral results strongly suggest that the presence of adult

cranes during antipredator conditioning of subadult cranes is of benefit. With the presence of an adult pair of cranes (models), subadult cranes show significantly more vigilance in the form of the tall alert behavior. Contact call and guard call occurrence were associated with age, however appropriate vocal response to predator presence occurred regardless of whether a model was present. No cranes were harmed during antipredator conditioning procedures, and time and money expenditures were minimal. Antipredator conditioning programs for cranes can be relatively simple and inexpensive with minimal risk to participants. We strongly recommend similar procedures be incorporated into other avian endangered species reintroduction programs.

INTRODUCTION

Historical Review of the Status of the Mississippi Sandhill Crane

John Aldrich first described the smaller darker Mississippi Sandhill Crane, *Grus canadensis pulla*, as a separate subspecies of the Sandhill Crane in 1972 (Johnsgard 1998). Mississippi Sandhill Cranes (MSHC) differ in their maturity rate and earliest egg production, making them physiologically distinguishable from other subspecies (Gee and Hereford 1995). This population is currently considered reproductively isolated from other Sandhill Crane populations (Miene and Archibald 1996). While the original distribution and population numbers for this subspecies are unknown, MSHC may have been contiguous with an extensive but widely scattered population of resident Sandhill Cranes along the coast of the Southeastern United States (Gee and Hereford 1995; Miene and Archibald 1996). The MSHC population originally occupied an area of South East Mississippi bordered by an east - west line roughly ten 10 miles North of Vancleave, in the south by Simmons Bayou, and extending from just east of the Pascagoula river to just west of Jackson county (Gee and Hereford 1995).

Prior to the 1940's, the wild population of MSHC, although small, remained stable. However, suitable habitat decreased from 100,000 acres to only 26,000 acres by 1960 due to agricultural and forestry practices as well as industrial development in part related to World War II ship building (Gee and Hereford 1995; Archibald and Lewis 1996). The Mississippi Sandhill Crane National Wildlife Refuge was created in 1974 by land donated from the Nature

Conservancy, the US Department of Transportation and the State of Mississippi (Gee and Hereford 1995). At its inception, 75% of land that was once crane savanna within the refuge had been subject to residential, commercial or forestry development (Gee and Hereford 1995). Currently, of the 19,300 acres that constitute the refuge, only about 12,500 can be used by cranes (Gee and Hereford 1995).

As early as 1938, as few as 100 birds may have existed in Louisiana, Mississippi, and Alabama, making the subspecies at risk of extirpation (Ellis et al 2000). By 1975, only 10-15 breeding pairs remained in the wild (Archibald and Lewis 1996). Current estimates of the MSHC population include 120 wild individuals and 20 captive breeding pairs; 75-80% of the wild population are either captive bred or direct descendents of captive bred birds (Miene and Archibald 1996). The US Fish and Wildlife Service added the MSHC to the endangered species list in 1973 (Gee and Hereford 1995). Additionally, Mississippi lists the MSHC crane as endangered and cranes are protected under the states Nongame Endangered Species Act of 1974. This nonmigratory population is considered the most endangered of the North American cranes with a conservation status of critically endangered (Miene and Archibald 1996) (Johnsgard 1998).

A recovery plan and priority conservation needs have been outlined for MSHC (Gee and Hereford 1995; Miene and Archibald 1996). The overall goal of this program is to "maintain a genetically viable, stable, self-sustaining, free-

living MSHC population” (Gee and Hereford 1995). Within that directive other pertinent objectives include: to identify “captive release conditioning necessary to maintain population size during restoration” or otherwise obtain “effective reintroduction of MSHC” and to “increase recruitment [and] reduce mortality” of Mississippi Sandhill Cranes (Miene and Archibald 1996). Research in the area of predator movement, predation affects on the population, and predator control and subsequent survival rates of the population has also been recommended (Gee and Hereford 1995).

Causes of Decline of Wild Mississippi Sandhill Crane Populations

While the anthropogenic influences of habitat disruption and degradation, and unrestricted hunting are certainly the leading cause of crane decline throughout the world, crane behavior is connected to many aspects of the population decline of cranes. Cranes’ specialized use of both wetlands and grasslands, make crane populations highly susceptible to the effects of habitat loss and degradation (Archibald and Lewis 1996; Reed 1999).

Genetic diversity of wild MSHC as measured by heterozygosity levels in multiple studies is roughly half that of other Sandhill Crane populations (Dessauer et al 1992). A reduction in successful breeding of the Mississippi Sandhill Crane is believed to be due to this lack of genetic diversity (Johnsgard 1998). In addition, detectable heart murmurs of the captive population, which may be genetically linked, appear to compromise the health of reintroduced birds and may be responsible for decreased survival (Gee and Hereford 1995).

An abnormally high rate of neoplastic disease in the form of adenocarcinoma, which may be secondary to an unknown pollutant, has also significantly decreased the population (Ellis et al 2000). Other diseases which may limit the population include microbial pathogens, parasites, and lead and mycotoxin toxicosis (Gee and Hereford 1995; Miene and Archibald 1996).

Predation is certainly a lesser threat to cranes than anthropogenic factors including habitat loss and degradation, and direct exploitation by humans such as hunting or disturbance. However, predation is listed as a threat to several crane populations throughout the world including Sandhill Cranes (*Grus canadensis*), Brolga (*Grus rubicundus*), Hooded Cranes (*Grus monachus*), Black-necked Cranes (*Grus nigricollis*), and Whooping Cranes (*Grus americana*) (Miene and Archibald 1996). Even though cranes have specialized vision enabling them to focus near and far fields simultaneously, they may be more vulnerable to predation, especially by man, because they are visible at great distances (Martin 1993; Reed 1999). In at least one refuge, the Malheur National Wildlife refuge in Oregon, predation is an important, limiting factor in successful wild Greater Sandhill Crane (*Grus canadensis tabida*) reproduction (Littlefield 1975).

The major classes of crane predators are avian and mammalian and chicks are the most vulnerable to predation (Lewis 1996). Mammalian predators of North American cranes (including eggs) include canids (wolves (*Canis lupus or rufus*), dogs (*Canis familiaris*), coyotes (*Canis latrans*)), foxes (*Vulpes* spp. or *Urocyon* spp.), bobcat (*Lynx rufus*) mustelids (Mustelidae), raccoons (*Procyon*

litor), and opossums (*Didelphis virginianus*) (Allen 1952; Littlefield 1975; Nesbitt 1981; Lewis 1996). Avian predators include ravens and crows (*Corvidae* spp.), jaeger (*Stercorarius* spp.), and raptors including Great Horned Owls (*Bubo virginianus*), Red Tailed (*Buteo jamaicensis*) and Red Shouldered (*Buteo lineatus*) hawks as well as Golden Eagles (*Aquila chrysaetos*) and American Bald Eagles (*Haliaeetus leucocephalus*) (Nesbitt 1981; Lewis 1996). Alligators (*Alligator mississippiensis*) are also a known cause of mortality in juvenile, reintroduced Whooping Cranes (Nesbitt 2002). Of juvenile MSHC released in the five years prior to this study's inception, 40% of deaths were attributed to predation and 60% to other or unknown causes. Of 31 juvenile MSHC deaths where causes were known, 65% of deaths were due to predation and 35% of deaths were due to other causes 35%. Thus predation remains the leading cause of death in released juvenile Mississippi Sandhill Cranes (Hereford 2002). Predation by bobcat is also a known cause of death in another subspecies of Sandhill Crane, the Florida Sandhill (Gee 2002).

Previous Reintroduction Programs of North American Cranes

While some individuals of each subspecies of Sandhill Crane are maintained in captivity throughout the United States, only MSHC are actively bred for reintroduction to the wild (Miene and Archibald 1996). The US Fish and Wildlife Service began breeding MSHC at the Patuxent Wildlife Research Center in Laurel, Maryland, in 1965. This flock has been divided between The White Oak Conservation Center in Yulee, Florida, and the Freeport-MacMoran Audubon

Species Survival in New Orleans, Louisiana (Miene and Archibald 1996). The goal of this breeding program remains to protect the subspecies during habitat restoration and provide stock for reintroduction (Gee and Hereford 1995). The Audubon Institute Center for Research of Endangered Species currently houses 15 breeding pairs of Mississippi Sandhill Cranes and is also one of only four U.S. facilities to house Whooping Cranes (*Grus americana*) (Unknown 1999). With almost 300 cranes released to date, the Mississippi Sandhill Crane project is the world's largest crane reintroduction effort (Ellis et al 2000). However, despite regular supplementary releases of captive-bred birds, reproduction in the wild population of MSHC continues to fall below replacement levels (Miene and Archibald 1996).

Multiple methods of rearing and conditioning captive-bred MSHC cranes prior to release have been attempted (Zwank 1987; Gee and Hereford 1995; Ellis et al 2000). Preliminary introductions of small numbers of captive-bred hand reared birds failed (Zwank 1987; Gee and Hereford 1995). Based on these observations, an initial 6 year study conducted at Patuxent Wildlife Research Center in the 1980's of reintroduction of captive parent-raised cranes to the Mississippi Sandhill Crane National Wildlife Refuge found that mortality of young cranes averaged about 50% (Zwank 1987). Most mortality occurred within the first year of release and predation accounted for 20% of crane deaths. Predators of juvenile MSHC noted in this study included canidae (*Canis familiaris* or *Canis latrans*), bobcat, and raptors. In addition, at least three cranes were

behaviorally unable to adjust to reintroduction to the wild. Two subadult cranes were hit by car and one was recaptured after unacceptable encroachment of a human area (shopping center). If cranes survived the first year of reintroduction, mortality decreased to less than 14% for the following years. The study noted a difference in predation among release sites with more predation occurring in the more densely wooded habitat where subadult cranes were thought unable to avoid predation. Although considered partially successful, the parent-rearing technique of this study was less desirable than hand-rearing techniques because of inherent low bird production and increased expenses incurred per bird (Gee and Hereford 1995). Parent rearing has also been associated with an increased risk of disease, parasitism, and accidents (Ellis et al 2000).

From 1989 to 1992, an effort to release more cranes per year through a new technique of costume rearing of cranes was begun at Patuxent Wildlife Research Center (Ellis et al 2000). Numerous techniques were employed by caretakers to assure proper imprinting and socialization of young cranes prior to release. Techniques included feeding young cranes with taxidermied heads of Sandhill Cranes, exposing young cranes to recorded or human simulated Sandhill Crane brood calls, costuming of caretakers in gray sheets to camouflage their human form, and exposure of young cranes to taxidermied adult cranes in brood posture with an accompanying heat lamp. Additionally, young cranes were exposed to live adult sandhill cranes at various stages of their development. A

predator control program of an intermittent and seasonal nature was also instituted on the refuge prior to juvenile crane reintroductions. This involved trapping predators large enough to kill full size cranes, with predators trapped averaging 33 per month during the study. While overall survival of reintroduced cranes (72%) was considered excellent and hand-reared cranes survived as well as introduced cranes, predation was still the leading cause of crane death. Of 17 cranes necropsied, 5 were confirmed and 2 were suspected to have died as a result of predation.

A similar example of juvenile crane predation is illustrated by the reintroduction program of the Whooping Crane. The last known nonmigratory population of Whooping Cranes within the US was extirpated from the wild by the 1940s with the last known birds residing in Louisiana. In 1993, The Florida Fish and Wildlife Conservation Commission, in cooperation with US Fish and Wildlife Service, US Geological Survey, Canadian Wildlife Service and other institutions, began reintroduction of Whooping Cranes to the Kissimmee Prairie (Nesbitt and Folk 2000). As of February of 2002, 236 cranes have been released however only 85 currently survive in the wild (Nesbitt 2002). Predation, predominantly by bobcat, causes mortality in approximately 40% of released cranes (Nesbitt 2002). In the spring of 2000, a pair of reintroduced Whooping Cranes successfully reproduced in the wild, hatching two chicks (Nesbitt and Folk 2000). Within 2 weeks, one chick was lost to unknown causes although this was not unexpected since chicks often commit siblicide. It is of note that the

remaining chick was killed by a bobcat shortly before fledging (Nesbitt and Folk 2000). Thus it would appear that, behavior modification that will allow cranes to avoid bobcats, coyotes, or other potential predators or their habitat would be highly beneficial to the recovery of the Mississippi Sandhill Crane and other endangered species of crane.

Predator avoidance conditioning has been used at the International Crane Foundation and the Patuxent Wildlife Research Center. Conditioning methods consist of exposure of young cranes to a predator (either human, avian, and / or mammalian) while a recorded guard call was played. Crane chicks were thought to be instinctively aware of avian predators but guard calls have been played during avian predator presence. This conditioning continues until all chicks are considered wary of the predator used (Nagendran et al 1996). While this training is scheduled every two weeks at some institutions, only chicks considered non-wary were exposed repeatedly. Unfortunately, the ages of crane suitable for conditioning were inconsistent varying from about 20 to greater than 45 days of age. Specific behaviors which may constitute predator awareness or antipredator behaviors were also undocumented. Whether this conditioning technique improves crane survivability has not been tested. Thus, a more controlled study of antipredator conditioning in juvenile cranes prior to reintroduction seems warranted prior to recommended application of this technique.

The current standard practice of soft release is based on known increased survival of reintroduced cranes when they feed and roost with wild cranes established in the release area (Nagendran et al 1996). It is possible then that reintroduced cranes learn wariness of predators from wild cranes at the release site (Nagendran et al 1996). However, preliminary comparative studies of foraging patterns of MSHC found that released MSHC did not adopt the foraging patterns of adult native cranes despite commingling and flocking together (Zwank et al 1988). It was thought that differing learned behaviors based on social learning or tradition in native cranes and prior exposure to foodstuffs in captivity in reintroduced cranes caused the observed foraging differences (Zwank et al 1988). This may indicate a critical learning period may occur prior to the age of reintroduction, which occurred between 4 months and 1 year for juvenile cranes in this study (Zwank et al 1988).

The adult Sandhill Crane, similar to other cranes, provides prolonged period of parental care to the young lasting about 10 months. The subadult crane is exposed to foods, roosting, migration pathways and wintering areas during this time period (Derrickson and Carpenter 1980). The complex repertoire of visual and vocal displays of cranes appears to be genetically determined or innate and independent of learning as blind cranes in captivity have shown a full complement of these behaviors. However, the object to which the display is directed appears to be learned as cranes can become imprinted and display to people (Archibald and Lewis 1996).

In many avian species, antipredator behavior appears dependent on learning and environmental experience (Borchelt and Ratner 1973; Lima 1993). Thus it would seem likely that during the parental period, young wild cranes would be exposed to a range of predators in the presence of adult cranes and, if necessary, learn to actively respond in an appropriate manner if necessary. Hence, while the aggressive or agonistic defense behavior seen in adults is likely inherent in the subadult crane, the appropriate direction of this behavior must be learned.

LITERATURE REVIEW

Causes of Decline of Endangered Avian Species

Factors in the decline of avian endangered species in the wild vary based on location, ecosystem, and species involved (Noon 1991). Destruction, degradation, and fragmentation of habitat remain major reasons for endangerment, decline and extinction of avian species (Ellis et al 1977; Triggs et al 1989; Noon 1991; Collar and Juniper 1992; Ardern et al 1994; Bunin and Jamieson 1995; Priddel and Wheeler 1996; Sanz and Grajal 1998; Heezik et al 1999). Competition by introduced species of plants and birds have also contributed to some avian species population declines (Kuehler 1996). Other factors causing decline of avian populations relate to human presence, especially hunting and poaching for the pet trade (Zwank et al 1988; Collar and Juniper 1992; Snyder et al 1994; Bunin and Jamieson 1995; Priddel and Wheeler 1996; Sanz and Grajal 1998; Heezik et al 1999). Disease plays a minor role in the endangerment of avian species as a whole, but disease has caused dramatic declines in some wild populations. Infectious and noninfectious diseases related to declines in avian populations include toxoplasmosis in the Bali Mynah, adenocarcinomas in the Mississippi Sandhill Crane, lead toxicity in the California Condor and the mosquito borne diseases of pox viruses and *Plasmodium* sp. in multiple Hawaiian species (Zwank 1987; Norton 1993; Kuehler 1996; Maretsky et al 2000). Predation of naïve island avifauna, especially by introduced predators, is a component of the extinction and endangerment of many avian species.

(Storey et al 1988; Triggs et al 1989; Haig et al 1990; Macmillan 1990; Ardern et al 1994; Robertson et al 1994; Bunin and Jamieson 1995). In most cases, a combination of all of the above mentioned factors are likely to be involved in the extinction of a species.

The Allee effect, defined as “any mechanism which can lead to a positive relationship between a component of individual fitness and either numbers or densities of conspecifics”, can also be conversely stated as any effect which causes declines in population growth rate at low population densities (Reed 1999; Stephens and Sutherland 1999). Until recently, this concept of population ecology was considered interesting but to have little application in ecological management (Stephens and Sutherland 1999). However it is now theorized that the Allee effect may have multiple applications regarding individual rarity and population fitness as it pertains to conservation of avian species. Beneficial effects of conspecific presence include predator dilution, increased antipredator vigilance in groups, and less energy spent on antipredator behaviors resulting in more time for foraging and offspring rearing. The Allee effect has in part been blamed for the extinction of the Passenger Pigeon (*Ectopistes migratorius*) which might once have been the most abundant North American bird species. This species may have suffered further insult after human exploitation and deforestation due to decreased foraging efficiency of reduced flock sizes (Stephens and Sutherland 1999). Allee effects can also depress early growth rates of introduced (or reintroduced) populations. Thus the likelihood of

establishing a population improves based on the number of individual birds that are released (Stephens and Sutherland 1999). In addition, it is theorized that predators can selectively target populations with low densities and when vulnerable species' populations decline below critical levels, predation can cause extinction (Curio 1998; Reed 1999).

Investigation and incorporation of aspects of avian behavior into avian conservation programs as a management tool is a relatively new concept (Sutherland 1998; Reed 1999). Reed categorizes behaviors that may predispose avian populations to endangerment or extinction in summary as: aggregations, lack of interspecific interactions during evolution of the species, inhibited dispersal, inappropriate habitat selection, and specialized or other behaviors that become maladaptive as change in selective pressure occurs (Reed 1999). Animal behavior studies have the opportunity to significantly contribute to animal conservation through multiple avenues including many relative to the topic at hand: identifying behavioral risk factors for small population extinctions, retaining cultural skills for reintroduction programs, behavioral manipulations to increase success of captive breeding programs, determination of behavioral habitat requirements for species conservation, and the possibility of the conservation of behavior as well as genetic variation (Sutherland 1998). It has been theorized that aspects of social behavior which affect juvenile and adult survival of a species will influence population growth rates (Caro 1999). Thus our study attempts to bridge the behavior conservation interface by measuring

fitness attained by birds after release which have been exposed to predators prior to reintroduction to the refuge.

The classical example of avian behavior resulting in increased susceptibility to predation is that of island avifauna lacking necessary behaviors due to inexperience or noncoevolution with introduced predators (Curio 1998). This predatory naiveté is historically blamed for the decline and ultimate extinction of the Dodo (*Raphus cucullatus*) and the Great Auk (*Pinguinus impennis*) (Reed 1999). More recently the extinction of the Carolina Parakeet (*Conuropsis carolinensis*) in 1924 can be attributed to this species' attraction to flock mate mortality which made the species more vulnerable to slaughter by man (Purcell 1999; Reed 1999). Aggregative breeding behavior in the Kakapo (*Strigops habroptilus*) may also increase this species susceptibility to predation (Cemmick and Veitch 1987; Reed 1999). One of the most compelling examples of avian extinctions caused by an introduced predator is that of the avifauna of Guam. Prior to the introduction of the brown tree snake in the 1940's (*Boiga irregularis*) 11 native forest birds were extant despite typhoons, bombings, introduced predators and land development (Haig et al. 1990). Seven of these species are now extinct and the remaining 4 species are critically endangered (Haig et al. 1990).

Shielding vulnerable avian species from predation in nature has been a successful means of protection from population decline and extinction (Curio 1998) Unfortunately predator removal is a costly and time consuming process.

Ethical and ecological issues of predator control programs must also be addressed including translocation or euthanasia. Additionally while predator removal appears to increase particularly vulnerable populations in the short term, the long term effects of predator removal for conservation are questionable. Analysis of results in 20 publications of predator removal programs intended to influence avian populations found unexpected results (Cote and Sutherland 1997). While removal of predators significantly increased the hatching success and post-breeding population sizes of many avian species, ultimately, breeding population size was not significantly affected. While both game species and endangered species were included in this review and breeding population numbers may have been affected by hunting or by inadequate census technique, this review also highlights other difficulties often encountered in predator removal programs. Few of the studies reported eliminating predators completely, even when all predators were targeted for removal. In addition, predator removal has little effect on bird populations when the ecological niche can be rapidly filled with another predator. One of the most significant and alarming findings of multiple studies was that predator removal was less effective in declining avian populations with three out of four investigations ultimately reporting failure of predator removal to alleviate continuing avian population decline (Cote and Sutherland 1997). Nonetheless, these findings included that predator removal can considerably and significantly reduce early avian mortality.

This finding may be of importance to our study, as it is early in the reintroduction process of juvenile MSHC wherein they are most susceptible to predation.

In island populations, if predators cannot recolonize once effectively eliminated, predator removal could have long term, lasting effects (Cote and Sutherland 1997). However, evidence suggests that mainland predator removal is without lasting effects and, without sustained predator removal efforts, benefits are quickly lost. Therefore, mainland predator removal programs must be a permanent management measure if other conservation measures are not undertaken (Cote and Sutherland 1997).

Similar studies of the Mallee Fowl (*Leipoa ocellata*), found the fox (*Vulpes vulpes*), an introduced predator, to cause substantial mortalities in adult and young introduced Mallee Fowl (Priddel and Wheeler 1994). Predation by foxes and raptors resulted in deaths of 94% of introduced birds, and provision of food for released birds had no apparent effect on survival of Mallee Fowl (Priddel and Wheeler 1994). While fox baiting increased survival of Mallee Fowl from 0% within 1 month to 29% at 3 months, the study concluded that intensive fox baiting would need to be frequent and widespread to reduce predatory densities to levels where predation would no longer prevent recovery of Mallee Fowl populations (Priddel 1997). This cause of mortality was thought to be underestimated in previous studies of this species. Another serious obstacle for successful reintroduction of Mallee Fowl was the lack of appropriate defense or

escape behaviors for evading predation by foxes. Young Mallee Fowl rely principally on camouflage to elude ground predators (Priddel and Wheeler 1994).

Models using predator-prey theory have been suggested to predict the rate of predator removal that is necessary to allow predator-prey coexistence compatible with species conservation. In addition, research to lessen prey vulnerability by allowing them to more effectively refuge at low population densities has been recommended (Sinclair et al 1998). Research of antipredator behaviors may be useful to provide insight into ways to lessen prey vulnerability.

Behavioral maladaptation to predation can have negative, population limiting, consequences for prey populations which are endangered as well as those which are unendangered. In a study of the decline of populations of the nonendangered Red Grouse (*Lagopus lagopus scotticus*), long-term population declines were attributed to habitat loss. However, raptor predation suppressed an expected population peak in the grouse population, and effectively limited the grouse population (Thirgood et al 2000). These findings indicate predation may also affect unendangered avian populations, especially when subject to low population densities.

In addition to the obvious effect of death, predators also have other, less evident, effects on the growth of prey populations (Lima and Dill 1990; Lima 1998). In Tropical Stonechats (*Saxicola torquata axillaris*), the presence of the Fiscal Shrike (*Lanius collaris*), a predator of adult and fledgling birds, was associated with high plasma corticosterone concentrations which are suggestive

of chronic stress as well as reduced body condition and likelihood of reproduction (Scheuerlein et al 2001). Predators may also cause prey populations to move to less viable habitat which may negatively affect avian populations (Lima and Dill 1990; Lima 1998).

Captive Breeding Programs of Endangered Avian Species

Captive breeding continues to play a key role in the preservation of some endangered avian species in the short term (Guam rail, *Rallus owstoni*, Mauritius kestrel, *Falco punctatus*, California condor, *Gymnogyps californianus*). However, captive breeding should be viewed as a last resort for species recovery, not a long term solution (Snyder et al 1996). Wild populations may still be more viable than captive populations when the problems encountered in captive breeding and reintroduction programs are considered. Captive breeding is not indicated approached as a species recovery tool simply because a wild population falls below a critical population level necessary to maintain the population in the wild.

Difficulties and limitations of captive breeding programs are well documented (Snyder et al 1996). Difficulties of sustaining captive populations have been encountered in captive breeding programs for the Kakapo (*Strigops habroptilus*), Whooping Crane (*Grus Americana*), and Hawaiian Crow (*Corvus hawaiiensis*). Reasons for encountering these problems can be related to the increased likelihood of infectious disease in captive populations or noninfectious disease such as infertility, inbreeding and/or lack of necessary husbandry requirements. However, behavioral problems are also a significant limiting factor

in sustaining captive populations. Specific examples include conspecific incompatibilities or inadequate mate selection, behavioral incompatibilities due to hand rearing, and/or lack of psychological requirements necessary for breeding in captivity. Poor success of reintroductions, high cost, and inherent domestication of captive raised animals, further hamper the effectiveness of captive breeding programs to augment wild populations (Snyder et al 1996). Many released birds suffer unexpectedly high mortality from predation (Curio 1998). A major disadvantage of captive breeding is that it disrupts the normal development of innate predatory recognition in birds (Curio 1998).

The goal of captive breeding is to increase the population above what could be attained in the wild by employing various techniques including double clutching (early egg removal to increase production), hand rearing and cross fostering. In addition, avian species held in captivity can be more closely monitored for disease processes and protected from causes of population decline including human encroachment or habitat destruction. Unfortunately, the progeny of captive breeding programs may show unacceptable behavior that results in birds being incompetent to breed or lacking other behaviors necessary for survival in the wild (Curio 1998).

In an attempt to overcome behavioral deficits of captive rearing, cross fostering, or the transfer of one species eggs or young to another species for rearing has been used. This has been used successfully in precocial species such as the plover and Killdeer (*Charadrius vociferus*). In a study comparing

cross fostered, hand reared, and wild reared Killdeer chicks, both hatching and fledging rates of hand reared chicks were improved over cross fostered and wild reared chicks (Powell and Cuthbert 1993). Growth rates of all age groups were similar and behavioral differences of chicks bred in captivity were not seen after they were released to the wild. All young Killdeer responded to wild adult Killdeer alarm calls, regardless of the rearing method. However, it should be noted that human exposure to all groups was minimized and that this species is predominantly precocial and self-feeding from the time of hatching. Assessment of subsequent survival and reproductive success were limited by the small sample size of the study (Powell and Cuthbert 1993).

In some avian species, notably cranes, the cross-fostering technique can lead to inappropriate sexual imprinting and problems of species recognition for reproduction (Horwich 1996). In the absence of fostering, it has been suggested that species with predominantly instinctive behavior, at the top of food chains, or species introduced to predator free or predator deficient environments may be better suited to reintroduction projects (Snyder et al 1996). Species whose behavioral repertoires are largely learned and have had all individuals drawn into captivity, may not fare well in reintroductions (Snyder et al 1994).

A study comparing hand reared and wild reared Snowy Plovers (*Charadrius alexandrinus*), showed that even in this precocial species, behavioral problems may occur upon reintroduction. After reintroduction hand-reared plovers took about 30 days to begin roosting with wild plovers and several

months to become wary at the approach of humans (Page et al 1989). In addition, more than half of released plovers (12 out of 22) disappeared by 7 months after reintroduction. While the reason for this disappearance was not determined, disappearance appeared unrelated to age. Although based on a small sample size, wild reared plovers began nesting earlier than hand reared plovers. Another important difference between hand reared and wild reared plovers was the increased proportion of hand-reared female plovers found to nest in lower quality habitat which negatively affected reproductive output (Page et al 1989).

Behavioral traits that are learned or culturally transmitted are rapidly lost in captivity. Thus captive populations may become resistant to reestablishment in the wild due to behavioral deficiencies within a single generation (Snyder et al 1996). For many species, captive breeding may result in progressive domestication, producing individuals with low establishment potentials or a decreased likelihood of survival in the wild upon reintroduction. (Snyder et al 1996).

Reintroduction Programs of Endangered Avian Species

Methods historically used to reduce predation in avian species have met with limited success. Each method has limitations and none are universally accepted (Armstrong and Ewen 2001). These methods include reintroductions - attempts to establish a species in part of its original habitat from which it has been extirpated or become extinct; translocation - deliberate movements of wild

individuals to other parts of their original habitat; reinforcements or supplementations - the addition of individuals to an existing population of conspecifics; and benign introductions - attempts to establish a species outside its recorded range but within an appropriate habitat and ecogeographical area (Curio 1998). One of the more successful examples of avian reintroduction is of the wild Turkey (*Meleagris galapavo*) wherein translocation of wild birds was an effective technique for reestablishment of this species throughout the United States (Dickson 1995).

Historically, reintroductions of endangered species have had a low success rate (11%) (Macmillan 1990; Snyder et al 1996). Further, the value of these programs may be considered even less, as a recent review of successful reintroductions after five years found that 5% of these projects had declining populations at the time of review (Seddon 1999). Captive-bred animals reintroduced in these programs have not had a high survival success rate (Snyder et al 1996). Serious behavioral deficiencies of captive-bred individuals, including predator avoidance, have been identified as factors in the failure of many reintroductions.(Snyder et al 1994; Snyder et al 1996). Many released birds suffer unexpectedly high mortality from predation (Curio 1998). These behavioral deficiencies appear more frequent in species that learn most of their behavioral repertoires or those that lack exposure to wild conspecifics during critical learning periods. Further, reintroduction attempts with captive-bred individuals facing significant predation risk often fail (Snyder et al 1994; Snyder

et al 1996). Disease exposure may also decrease the likelihood of success in reintroduction efforts. Mosquito transmitted disease negatively affected the Hawaiian reintroductions of the Amakihi and the Hawaiian crow or Alala (*Corvus hawaiiensis*), however, some species can survive disease entities with treatment (Kuehler 1996).

The likelihood of success of avian reintroductions increases with the number of reintroduction periods, the number of birds reintroduced, the number of places reintroduction occurs, and increasing age (irrespective of size) (Priddel and Wheeler 1996; Green 1997; Curio 1998). Some reintroduction projects of captive-bred birds have documented survival, appropriate flocking, and reproductive success (Sanz and Grajal 1998). Notably in this project, birds were subject to predation prior to release (Sanz and Grajal 1998). A recent review of avian and mammalian translocations (a technique similar to reintroductions) identified factors associated with success including release into the center of the original range, good quality habitat, use of native game species, and omnivorous diet of the released animals (Wolf et al 1996). Unfortunately, birds were less likely to have successful reestablishment than mammals. While this study found several factors were not associated with reestablishment after reintroduction including the species reproduction potential, the number and duration of releases or whether animals released were wild caught or captive reared, the inclusion of mammals in the analyses may have negated the applicability of these results to avian reintroduction programs.

Establishing high levels of genetic diversity in a population is indicated since genetic variation could positively influence population growth rate and subsequent size, the populations ability to adapt to environmental conditions. However this theory has seldom been tested in natural environs. In a study of mosquito fish populations, increased genetic variability did not enhance population size or growth. To the contrary, size of outbred populations tended to be smaller, an effect of outbreeding depression. However this model may not directly relate to endangered species wherein small populations have existed for multiple generations as mosquito fish populations typically have high levels of genetic diversity and large numbers of individuals (Leberg 1993). The level of genetic diversity did not appear to be causative in the continuing decline of a reintroduced population of eastern wild Turkeys (*Meleagris gallapavo silvestris*) (Harmon and Bussche 2000).

Deleterious effects of supportive breeding such as a reduction in the genetically effective population size, or a reduction in genetic biodiversity, have not been studied in birds. However in other species, where generation times are shorter, the genetic effects of successive generations of supportive breeding wherein the overall population is increased may increase the genetically effective population size (Wang and Ryman 2001).

Assessment of the reestablishment of endangered avian species can only be accomplished through long-term monitoring after reintroduction (Seddon 1999). Suggested definitions of reestablishment success vary from objectives

which may be monitored in the short term such as breeding by a wild born first generation, or a three year breeding population in which recruitment exceeds the death rate. More long term definitions depend on the establishment of self-sustaining or unsupported populations of a defined number of individuals. The definition of successful reintroduction depends largely on characteristics of the population in question. However, the objective of establishment of a self-sustaining population without intervention should attain three ordered goals: survival of the release generation, breeding of the released generation and finally, persistence of the released population (Seddon 1999).

Overview of Avian Antipredator Behavior

Interspecific responses in birds, especially antipredator behaviors, have been studied under laboratory and field conditions. Antipredator behavior refers to any behavior by which the prey animal may escape or otherwise avert predation. Antipredator behavior in birds includes multiple forms of escape, however no escape behaviors have been documented in cranes; this lack of documentation has been attributed to their large size (Lima 1993). Other antipredator behaviors of birds including freezing, death feigning or tonic immobility, high intensity vocalizations, withdrawal and crouching, and silence have been investigated in the ring dove (*Streptopelia risoria*), the domestic chicken (*Gallus domesticus*) the bobwhite quail (*Colinus virginianus*), and the Japanese or domestic quail (*Coturnix japonica*), the wren (*Troglodytes aedon*), the ptarmigan (*Lagopus lagopus*), the Stone Curlew (*Numenius*

americanus) and the turkey (*Meleagris gallapavo*) (Vowles and Prewitt 1971; Borchelt and Ratner 1973; Rovee et al 1977; Suarez and Gallup 1983; Stahlbaum et al 1986; Hill et al 1994; Mills et al. 1997). Tonic immobility is characterized by the absence of the righting reflex, assuming a catatonic posture, intermittent eye closure and suppression of vocalization (Suarez and Gallup 1983). However, none of these specific antipredator behaviors have been documented in the crane.

Vigilance, defined as scanning or alert behavior, is found in many avian species and appears affected by multiple factors. Birds in large groups appear to spend less time scanning their environs, leaving more time for feeding, nesting or reproduction, when compared with single birds or smaller groups. This theory, called the group size effect, has been supported by behavioral observations in multiple bird species including Sandhill Cranes, Spice Finches (*Lonchura punctulata*), and Greater Rheas (*Rhea Americana*) (Tacha 1981; Martella et al 1995; Beauchamp and Livoreil 1997). Thus better foraging efficiency or better predator avoidance are considered benefits of avian group living (Lima et al 1999; Jullian 2000). In addition, flocking or colonial breeding may provide reduced individual risk of predation and increased defenses at less individual cost (Conover 1987; Cresswell 1994; Winkler 1994; Jullian 2000; Arroyo et al 2001). Birds on the edge of a group are thought to exhibit more vigilance. This is known as the group edge effect (Rattenborg et al 1999). Increased density of vegetation or a reduction in visibility due to habitat is also associated with

increased vigilance in bird species including the Greater Rhea, Turnstones (*Arenaria interpres*) and Purple Sandpipers (*Calidris maritime*), and Temminck's Stint (*Calidris temminckii*) (Metcalf 1984; Martella, Renison et al. 1995; Koivula 1998). However, recent studies of Dark-eyed Juncos (*Junco hyemalis*) suggest that nonvigilant birds may still be able to detect predator attack, although detection ability is greatest when birds heads are raised (Lima and Bednekoff 1999).

In the Great Tit (*Parus major*), dominance is positively correlated with the amount of time spent being vigilant (Krams 1998). Some species also increase vigilance during incubation and egg laying periods (Jacobsen 1992). Vigilance and other antipredator behaviors may or may not be affected by gender, but when these behaviors are affected, males appear to show more antipredator behaviors (Buitron 1983; Martella et al 1995; Beani and Dessi-Fulgheri 1998). In studies of captive Grey partridge behavior, (*Perdix perdix*), more vigilant partridge males pair-bonded earlier than other partridge males (Beani and Dessi-Fulgheri 1998).

Distress calls are described as high pitched calls given upon separation from conspecifics in the absence of predatory threat. These calls appear to promote brood reunion or maternal retrieval and may be more appropriately called contact calls. These types of calls have been documented in numerous avian species including the domestic chicken (*Gallus gallus domesticus*), the Burmese Jungle Fowl (*Gallus gallus spadiceus*), the Bobwhite Quail (*Colinus*

virginianus), and the duck (*Anas platyrhynchos*). Fear stimuli decrease distress calls, likely an adaptive strategy to avoid predation, the consequences of which would outweigh the initial goal of social reinstatement (Suarez and Gallup 1983). Contact calling and walking are delayed in chicks and ducks by exposure to electric shock, a stimulus which compares with predation by providing restraint, contact and pain. Distress calling may also be more effectively suppressed by increasing sound stimuli (Suarez and Gallup 1983). In field studies of chickens, contact calling decreased with increasing age, isolation or decreased socialization. Contact calling and tonic immobility wane if birds are habituated to predators or human presence (Suarez and Gallup 1983).

Conversely, vocalization may increase the chances of predation in numerous avian species (Chandler and Rose 1988). In studies using Crested Tit (*Parus cristatus*) models accompanied by recordings of long-range Crested Tit contact calls, models were attacked significantly more often by Sparrow Hawks (*Accipiter nisus*) than models without recordings or those accompanied by only high pitched sounds. This provided evidence for the theory that contact calls of this species could attract predators (Krams 1998). Play-back experiments of mate attraction calls of Blue Petrels (*Halobaena caerulea*) demonstrated that these calls were used as a cue by their predator, the Brown Skua (*Catharacta antarctica lonnbergi*), for prey location and selection (Mougeot and Bretagnolle 2000). To the authors knowledge, this association has not been investigated in scenarios of avian prey and mammalian predators.

Antipredator behavior of birds may also be affected by the stimulus presented by the predator. Studies of antipredator behavior of avian mobbing in response to taxidermic Eastern Screech Owls (*Otus asio*) with and without recordings of Eastern Screech Owls, or only recordings of Eastern Screech Owls revealed differentiated antipredator behaviors (Chandler and Rose 1988). Trials included avian responses from 85, predominantly passerine, species. Birds were more effectively drawn to the testing site by recordings but mobbing behavior was more likely to occur and occurred more intensely and for a longer duration when the Eastern Screech Owl model was present, rather than only the recording.

Documentation of the behavior of birds in response to predators has largely been anecdotal, observational or descriptive (Mueller 1975; Lima 1993). Controlled studies where behavioral responses have been recorded in response to predators are few. Avian behavior is a critical factor in recent avian extinctions and endangerments (Reed 1999). In a comparison of the flightless Australian Takahe (*Porphyrio mantelli*) and Pukeko (*Porphyrio porphyrio*), fewer antipredator responses (distance from the model, time present, vigilance, tail flicks, wing flaps, alarm calls) to the taxidermic predator by the Takahe were associated with declining populations (Bunin and Jamieson 1996). In a study of predation by Red Foxes (*Vulpes fulva*), a significant number of ducks (Mallards (*Anas platyrhynchos*), Pintails (*Anas acuta*), Blue-winged teal (*Anas discors*), Wood ducks (*Aix sponsa*), and Lesser Scaup (*Aythya affinis*) survived initial

capture and handling by foxes due to tonic immobility, an antipredator behavior characterized by motor inhibition, catatonic paralysis, waxy flexibility and remaining quiet and unresponsive in response restraint (Borchelt and Ratner 1973; Sargeant and Eberhardt 1975; Hill et al 1994). In the laboratory setting, tonic immobility of Japanese Quail proved an effective deterrent of predation by domestic cats (Suarez and Gallup 1983).

Diurnal and seasonal variation also affect avian antipredator behavior. The twilight hours of morning and evening are when mammalian predators are more active, and in domestic fowl it is during this time that antipredator behavior peaks (Hill et al 1994). Antipredator behavior may also vary with the season. In the Robin (*Turdus migratorius*), antipredator behaviors became more agonistic tending toward attacking and mobbing, only in the seasons which they held territories (March through August) and the degree of mobbing was increased by the presence of young (Shedd 1982). Similarly, in a study of multiple passerine species, responses to taxidermic owl models and owl call recordings were subject to increased attraction and mobbing during the summer months (Chandler and Rose 1988).

Recent research indicates that birds have additional antipredation abilities at night. Only birds and aquatic mammals share the feature of unihemispheric slow wave sleep (USWS) (Rattenborg et al 1999). In aquatic mammals, USWS allows breathing and sleep to occur concurrently in water. However, recent studies of Mallard Ducks (*Anas platyrhynchos*) suggest that USWS serves to

detect predators. Four birds were arranged in a row and eye state and EEG were recorded. Theoretically, the concept of group edge effect predicts that edge birds will be more vigilant. Results showed that edge birds were more likely to have the eye directed away from the group open, and showed an increased USWS compared to central birds. Further when the edge ducks' open eye was exposed to threatening visual stimuli, these ducks responded rapidly. Thus birds are not only able to detect approaching predators through the use of USWS, they are also capable of modulating USWS use under conditions where predation may be more likely.

Few studies of antipredator behaviors of subadult birds have been described. Both field and laboratory studies of this type provide logistical challenges because of difficulty in viewing subjects, in interpreting group behaviors, and determination of when to begin testing after hatching. Recent studies on the Australian Brush Turkey (*Alecturi lathami*) provide an excellent model to study truly innate antipredator behaviors in the young bird (Goth 2001). This species' interesting life history involves hatching independently underground, and emerging to lead a single, precocial life without parental or adult conspecific involvement. Behavioral comparisons of hatchling response upon exposure to live predators (cat, dog) model predators (raptor silhouette, rubber snake) and controls of similar shape and size found no difference of hatchling behavior towards predators and controls. This suggested that antipredator response was based on size, dimensions, height, and/or relative

speed, rather than the specific predator. Increased vigilance during playbacks of song bird alarms calls than during playbacks of white noise (control) indicated an innate response of Australian Brush Turkey chicks to songbird alarm calls. Thus in megapodes, and possibly other avian species as well, antipredator behavior of the chick may initially be innate.

In several avian species such as the Wren (*Troglodytes aedon*), Ptarmigan (*Lagopus lagopus*), Bobwhite Quail (*Colinus virginianus*), Stone Curlew (*Numenius Americanus*), Turkey (*Meleagris gallopavo*), adult birds exhibit freezing and silence upon detection of a predator (Suarez and Gallup 1983). The young of these species and even hatched ducklings denied maternal contact, showed similar behaviors of freezing and silence in response to adult conspecific alarm calls. The obvious advantage of these antipredator behaviors is to elude detection and therefore predation. Parental influence may strongly affect antipredatory behavior in some birds. In studies of antipredator behavior in Grey partridges in response to raptor models, raptor calls, and Grey Partridge alarm calls, the antipredator behaviors of freezing and vigilance occurred more in parent-reared Grey Partridges than in those reared without parental influence (Beani and Dessi-Fulgheri 1998). In Moustached Warblers, chicks reacted differentially to predator types, remaining in the nest for aerial predators and jumping from the nest for ground predators (Kleindorfer 1996). The antipredator response of chicks was dependent upon adult alarm calls. In Lapwings, appropriate antipredator behavior of chicks in the form of crouching or evasive

action was induced by the differing adult alarm vocalizations based on the presence of terrestrial or aerial predators. Although no obvious communication of predator identity was observed, theoretically the graded call of Lapwings could permit specific communication between adults and young (Walters 1990).

Many antipredator behaviors observed in the wild suggest an inherent learning component. Observations of Ring-Billed Gull colonies suggested that predator-attraction behavior allows gulls to learn about predators from watching predator conspecific interactions, a benefit of coloniality for these birds (Conover 1987). Observations of both hand-raised and wild Magpie fledglings suggest an innate fear response of hatchlings which was modified by the behavior of parent and other adult magpies as well as by their own experiences (Buitron 1983).

Predator avoidance mechanisms in animals may be innate (not require predation experience) or depend on learning and or environmental experience, or a combination of both (Borchelt and Ratner 1973; Lima 1993; Curio 1998). Innate antipredator behaviors have been documented in both domestic and wild avian species including the Bobwhite Quail, the domestic quail, and the domestic chicken (Rovee et al 1977; Stahlbaum et al 1986; Hill et al 1994). Innate predator recognition has been described in the Seychelles Warbler (Veen, et al 2000). The social environment may affect antipredator behavior through pseudoconditioning, improvement and or maintenance these behaviors through parental reinforcement, or by cultural transmission of antipredator behavior via conditioning to predator stimuli. The predator itself may instill avoidance as well

(Curio 1998). Birds have innate antipredator behavior, but the social environment modulates these behaviors (Curio 1998).

Crane Antipredator Behavior Review

Sandhill Crane behavior has been documented extensively. Those behaviors documented or deemed desirable in response to predators and other behaviors consistently observed in the subjects of our study are detailed below. The following section reviews these behaviors in detail, labels them and describes, when possible, if they have been described in the field or in captive cranes, what ages the cranes were when these behaviors were first displayed and under what circumstances the behavior was performed.

The species or subspecies is noted and the common names of Greater Sandhill, Florida Sandhill and Mississippi Sandhill will be used synonymously with *Grus canadensis tabida*, *Grus canadensis pratensis* and *Grus canadensis pulla* respectively. The predator in each situation will also be detailed. These behaviors are stereotypical and are shared among species of cranes and may be expected in all individuals although they have been described in only a few (Ellis et al 1998). The behaviors are arranged from flight to defensive to aggressive (least to most agonistic) and where certain behaviors accompany others, this is also noted. Lastly, additional known behaviors of immature Sandhill Cranes which may be useful in predator evasion are reviewed.

In the **Preflight Posture** or **Neck Stretch Display**, the crane's neck is stretched forward and up and the crane faces into the wind. A neck fluff version

(suggesting fear) of this is seen in the Sandhill Crane (Ellis et al 1998). Tacha also describes wing flapping and “leaping into the air with wings outspread and flapping” as displays that signal flight as an option (Tacha 1981). Frightened sandhill cranes may proceed from this posture to “neck-stretch-wing-spread-run” along with an alarm call.

Preflight Calls or **Flight Intention** calls are brief honk-like hoarse gargles given in long series with about one call per second. This is seen in birds preparing to fly and usually accompanies preflight posture (Ellis et al 1998). The preflight call was observed in captive reared Greater Sandhill Crane chicks at 11 weeks of age (Voss 1976). However, another author working with wild Sandhill Cranes noted no preflight call prior to take off, only the occasional alarm call (Tacha 1981).

The **Alert Posture** or **Tall Alert** has been variably described as an agonistic or an ambivalent behavior (Voss 1976; Ellis et al 1998). In a population of sandhill cranes from midcontinental North America (*Grus canadensis*), the tall alert is described as:

The body axis was held near vertical, elevating the head with maximum extension of the neck. The bill was held horizontally, feathers flattened against the body and no motion or sound was evident (Tacha 1981).

This behavior appears to not only gather information for the individual but also to be contagious in order to deliver a message to cranes in the vicinity that

danger is near (Tacha 1981). Another account of this posture in Greater Sandhill Cranes describes the cranes' movements as tense, and further states that the neck appears thinner and the carpi more prominent due to the flattening of the feathers (Voss 1977). This posture was observed in captive Greater Sandhill Cranes responding to humans, dogs, hawks and crows, and in wild Sandhill Cranes responding to aircraft, cars, trucks, tractors, and humans (Voss 1977; Tacha 1981). This behavior was observed in wild Florida Sandhill Cranes in which it was directed toward a Red-tailed Hawk flying overhead as well as Ibis and a Snow Egret (Layne 1981). In mated pairs, the male is generally the dominant bird and will tend to show more alert behavior (Ellis et al 1998). Males tend to extend the head and neck upward while females tend to extend the neck forward. Correspondingly, dominant males probably assume a greater role in threat detection (Ellis et al 1998).

The **Contact Call** likely functions to keep pairs and families of cranes in auditory contact, especially in dense habitat which could obscure visual contact of small chicks (Voss 1976). Described as a steady trill of 0.2-0.4 seconds the interval of calling varies from 1-2 times per second to a call given every few seconds (Voss 1976; Ellis et al 1998). Chicks may give this call almost continuously, however adult cranes give this call regularly but less often. The contact call of immature cranes begins before hatching, has a higher frequency and has been called a peep (Voss 1976; Ellis et al 1998). This call is described as a brief quiet whistle which may change to a brief chirp or extend into a purr (Ellis

et al 1998). At 48 weeks, subadults begin to give the lower adult contact call (Voss 1976), described as a quiet brief hoarse gargle (Ellis et al 1998). This call, due to its quiet nature, is difficult to discern in the wild.

The **Alarm Call** is brief loud low frequency blast composed of subnotes given so quickly as to be inseparable to the human ear. This call is given upon detection of a distant predator or threat (Ellis et al 1998). This behavior was first observed in captive reared Greater Sandhill Crane chicks at 9 weeks of age (Voss 1976). This call may be given prior to preflight posture followed by flight (Voss 1977).

The **Guard Call** is described as a series of short, loud vocalizations composed of guttural squawks separated by several seconds (Voss 1976; Ellis et al 1998). These are uttered in response to distant disturbances, including predators, or to defend territory (Swengel et al 1996; Ellis et al 1998). This vocalization is associated with an element of fear or a tendency to flee and has been noted with the approach of dogs, strange humans, or hawks or crows overhead. The guard call develops in captivity between 9 and 19 weeks of age in captive-reared Greater Sandhill Cranes (Voss 1976; Voss 1977). Guard calls have been observed in wild Florida Sandhill Cranes in response White Ibis, Snowy Egret and cows (Layne 1981). The guard call and unison call of the Greater Sandhill Crane appear to exhibit functional overlap based on the continuum of threat present. Lesser threats, which are also less likely to cause flight, tend to elicit the guard call while greater threats may elicit either a guard

call and/or a unison call (Voss 1976). In the Sandhill Crane, this call may be given less often in response to an intruder than the unison call which may also be used for the conspecific intruder (Swengel et al 1996). "Broken guard calls" of higher frequency but identical pattern were noted in wild Greater Sandhill Cranes estimated to be 18-25 weeks in age when adult birds unison called (Voss 1976).

The **Unison Call** is a sexually dimorphic call of indeterminate length performed by paired cranes of all subspecies of Sandhill Crane (Voss, 1977; Ellis et al 1998). In the Greater Sandhill Crane, the pair may be up to 100 m apart and exhibit crown expansion, raised tertial feathers and keep the wings folded against the body when calling (Voss 1977, Ellis et al 1998). The body is kept close to horizontal while the neck remains nearly vertical (Voss 1977). A tiptoe stance, resulting in a relative height increase, is associated with increased aggression in all subspecies (Ellis et al 1998). During calling, the female crane's bill is held 45 degrees above horizontal while the male crane's bill is almost vertical (Voss 1977). Between calling, the female's bill is held horizontally while the male's bill may remain vertical or be lowered to only 45 degrees above horizontal in more aggressive encounters (Voss 1977). The call begins with a brief high-pitched introductory call given by the female which is quickly followed by the male's lower broken call (Voss 1977). Both cranes then begin a regular series of synchronous calls wherein each longer, lower call of the male crane is answered by two shorter calls of the female (Voss 1977).

This unison call may function as an aggressive display in the wild Sandhill Crane, with calling occurring by the pair prior to physical aggression or after driving an intruder from their territory (Nesbitt 1981). In wild Greater Sandhill Cranes, increased unison calling has been associated with sunrise and sunset, territorial defense and nesting (Voss 1977). Unison calls have been reported in captive Greater Sandhill Cranes as young as 10 months of age (Voss 1976).

Bunching has been described in Greater Sandhill Cranes in response to avian predators. In this behavior cranes rush into a compact group and point bills skyward to deter predator attack (Ellis et al 1998).

Hiss is a loud hissing noise, usually emitted during preattack displays or attacks (Ellis et al 1998).

The **Crouch Display** and the Wing Spread Display are considered the most agonistic postures given prior to attack. Cranes lower to an incubating posture, spread their wings and make bill contact with vegetation. This behavior may be a ritualized form of incubation, signaling the intruder that the crane has a great investment in the area such as nesting (Ellis et al 1998). This display, accompanied by a charge at conspecifics, was first noted in captive-reared Greater Sandhill Crane chicks at 11 weeks of age (Voss 1976). This author did not observe this behavior in the presence of predators (Voss 1977). Further, the author observed this behavior in wild Greater Sandhill Cranes but it was directed at conspecifics not predators (Voss 1977). In contrast, others only describe this behavior in wild Florida Sandhill Cranes and in a single, young Greater Sandhill

Crane and suggest that this display transmits little or no agonistic information (Nesbitt 1981).

The **Wing Spread Display** is seen as a crane approaches or backs away from an intruder before or after attack. The crane will spread (half open) and droop its wings so primary and secondary tips droop or touch vegetation. The neck is extended upward and slightly forward with the crane's head and beak facing the antagonist (Swengel et al 1996). The alarm call, guard call and or hisses often accompany this display (Ellis et al 1998). This display has been described in Sandhill Cranes as young as 6 weeks of age and elicited in captive adult Greater Sandhill Cranes exposed to dogs (*Canis familiaris*) and a captive Red Tailed Hawk (Voss 1977). This display has been reported in wild adult Florida Sandhill Cranes in response to a cow (Layne 1981). It has also been described as directed toward an adult Canada goose and mammalian predators (Voss 1977; Nesbitt 1981).

Mobbing, run-flap, bill-stab, jump-rake, and wing-thrash behaviors are thought to be displayed by all species of cranes and are used in attempt to dispel or kill an intruder (Ellis et al 1998). **Mobbing** is a when a group of cranes rush at a predator (Ellis et al 1998). While this behavior has not been documented in Sandhill Cranes, one author assumes that all cranes exhibit this behavior (Ellis et al 1998). **Run Flap** is simply running while flapping (Ellis et al 1998) which may be exhibited prior to attacking, or while fleeing. **Bill Stab** or **Bill Sparring** is described as a rapid thrust of the open or closed bill intended to injure the

target. Bill stabs by cranes have killed humans and dogs (Ellis et al 1998). In wild Greater Sandhill Cranes, bill sparring was observed more often in male cranes (Nesbitt 1981). In the **Jump Rake** or **Chasing and Kicking** behaviors, the crane runs toward the predator with its neck stretched 50 degrees above the horizontal, leaps into the air, and slashes at the predator with its talons in attempt to inflict injury (Voss 1977; Ellis et al 1998). The **Wing Thrash** consists of rapid, repeated slapping of the wings against the predator. This behavior is thought to confuse the intruder rather than cause real injury (Swengel et al 1996). As a group, these aggressive behaviors have been described in wild adult Greater Sandhill Cranes defending a nest from bald eagles (*Haliaeetus leucocephalus*) and moose (*Alces alces shirasi*) (Altmann 1960; Nesbitt 1981). Cranes may also use stealth to approach an intruder: cranes circuitously walk closer and closer to the intruder while feeding, then abruptly rush the intruder (conspecific or predator). This can lead to an aerial pursuit, and possibly slashing with the talons during flight (Swengel et al 1996).

Documentation of behavior in young wild cranes in response to predators is limited because behavioral observation may be obscured by vegetation as well as the protective coloration of the hatchling. Voss suggests that the major antipredator strategy in young cranes prior to the development of flight capabilities (9-10 weeks) may be hiding (Voss 1976). This suggestion is based on an unsuccessful banding attempt of an 8-week-old Greater Sandhill Crane chick which effectively disappeared in vegetation as parent cranes took flight and

could not be located. This young crane reappeared 10 minutes after human departure upon return of the parent cranes.

Young crane responses to predator aversion conditioning include running, hiding, and flight. These are likely to be normal avoidance responses to predators (Nagendran et al 1996). Pacing has also been suggested as a sign of insecurity in Red-Crowned Crane (*Grus japonensis*) chicks and may have been related to a threatening stimulus (Horwich 1987). In the wild, a subadult Sandhill Crane of 18-25 weeks of age was observed to direct the agonistic behaviors of jumping, kicking and repeated flapping (chasing, kicking, and wing thrashing) toward another chick (Voss 1976). Other behaviors documented in one week old captive-raised Greater Sandhill Crane chicks which might be used for predator aversion include wing flapping, jumping and running (Voss 1976). These chicks first showed aggression toward humans at the 39th week of age (9 months) (Voss 1976). Nesbitt reports that wild subadult Greater Sandhill Cranes exhibit all of the aggressive displays mentioned above but with a reduced frequency and intensity when compared with adult males. However only plumage observation was used to determine an approximate age of less than one year in these cranes and what these aggressive behaviors were directed toward was not mentioned (Nesbitt 1981).

Crane chicks are prone to sibling aggression and siblicide. It is rare for a pair of cranes to raise two chicks due to siblicide even though 2 eggs are usually laid. This aggression between chicks is greatest in the Greater Sandhill Crane and

the Whooping Cranes; therefore these species are never housed communally, especially when very young (Derrickson and Carpenter 1983; Unknown 1993; Wellington et al 1996). The first aggressive displays towards other chicks in Greater Sandhill Crane chicks were noted at 6 weeks of age. Prior to this age introduction of other chicks resulted in outright attack (Voss 1976). Aggression towards other chicks seems to wane at about 3 months of age, when juvenile contour plumage has replaced most of the down (Derrickson and Carpenter 1980). Aggression towards humans was noted to develop at 42 weeks of age, in captive-reared Greater Sandhill Cranes.

Avian Cognition and Learning Abilities

The central question relevant to any avian conditioning program is do birds have the ability and intelligence necessary to learn? Early studies of chickens and pigeons concluded that avian intelligence was minimal, however today it is thought that many avian species have mental abilities that rival those of mammals, nonhuman primates and even humans (Pepperberg 2001). Initial studies were hindered by accepted concepts of differential mental abilities between species as well as acceptance of neuroanatomical correlations of cerebral cortical size and intelligence in mammals. Birds which cache food for later use have superior spatial abilities, whereas birds with vocal abilities are better suited to learning auditory differences. While relative cortical size is thought to correlate with cognitive ability in mammals, the striatal areas of the brain appear to correlate better with learning and memory abilities in birds.

Studies using cognitive problems have shown birds with greatest striatal development (crows, parrots and mynahs) performed more accurately than birds with less striatal development (pigeons and chickens) and better than some nonhuman primates. Further, lesions in the striatal areas of the brain appear to interfere with avian learning. Thus, it appears that a large cerebral cortex is not necessary for cognitive tasks in birds. Conceptual learning may be tested by assessment of whether a learned skill transfers to a conceptually similar but novel problem (Shettleworth 2001). Grey parrots respond as well on new problems as on related training problems; This ability to transfer information between problems is evidence of advanced cognitive capabilities (Pepperberg 2001).

In a review of avian cognition, Pepperberg summarized the findings of researchers attempting to demonstrate the mental abilities of birds in the areas of categorization, the concept of same/different, numbers, spatial ability, tool use and communication (Pepperberg 2001). To some extent, birds have demonstrated aptitudes, sometimes equal with that of humans, in all of these areas. Birds have the ability to sort surroundings into definable entities or categorize. Nature necessitates birds categorizing items of shelter or not, mate or not, food or not, or predator or not. Laboratory testing demonstrates that pigeons can discriminate between visual images of trees or people. Many passerine species can differentiate song types from their species or other species, and some passerines can determine if songs come from certain

individuals. The concept of same-different has been more difficult to assess in birds, however, pigeons comprehend the concept of same but not different. The ability to discern quantity has also been demonstrated in birds. Many birds can learn to eat a specific number of items, and canaries can select a subset of items within a set or specifically numbered item within a set. While pigeons recognize more versus less, the ability to quantify may be affected by overall mass of the object, especially when food is used as the numbered object, similar to findings in chimpanzees. Grey parrots, jackdaws, and ravens (*Corvus corax*), can match quantities up to 8, pigeons up to 6, and chickens up to 3. In addition wild bird species such as Crows (*Corvus brachyrhynchos*), Sparrows (*Melospiza lincolnii*), finches, Wood Peewees (*Contopus virens*), and Blackbirds (*Turdus merula*), use quantifiable sequential auditory patterns for identification of flockmates or to change their response. Although birds recognize certain numbers of objects or song repetition, no birds appear to count in the human manner.

Spatial memory is an ability in which some avian species excel (Pepperberg 2001). Object permanence, the concept that an object continues to exist when not visualized by the observer, has been demonstrated in psittacids and possibly Magpies (*Pica pica*) at a level equaling primates. Remarkable memory has been demonstrated in caching birds such as Clark's Nutcracker (*Nucifraga columbiana*), which could recall the location of 10,000 seed storage sites for as long as 9 months. Birds remember sites which they have emptied and those that are still full, perhaps by the mechanism of selective forgetting of

emptied sites. Scrub Jays (*Aphelocoma coerulescens*) and Black Capped Chickadees (*Parus atricapillus*) can also remember the type of food item stored and select sites to check based on the length of food storage or the favored food item. These actions are suggestive of episodic memory, or recall of past personal experience (Shettleworth 2001). An interesting neuroanatomical correlate in caching birds is that they have a relatively large hippocampal area of the brain, which is associated with memory and spatial behavior (Pepperberg 2001).

Tool use requires the performance of complex actions in order or synchrony and often involves learning muscular set coordination (Pepperberg 2001). The ability to use tools implies advanced cognition. For an object to qualify as tool, certain criteria should be met: The object must be detached from the substrate or body of the user, the user must hold or carry the object and correctly orient it to the task and the tool must change the item at which it is directed. Lastly, some level of object manufacture has been suggested as necessary to qualify the object as a tool. Corvids have fulfilled all the qualifications of tool use. Blue Jays (*Cyanocitta cristata*) tore paper to obtain food otherwise out of reach. Tool use in New Caledonian Crows varied based on traditions of the area they were from, suggesting that the ability to use tools is learned rather than instinctual in birds (Pepperberg 2001).

Communication is another area where the mental abilities of birds appear to equal nonhuman primates. Preliminary studies suggest that many psittacids (Maroon-Fronted Parrots (*Rhynchopsittica terrisi*), White Fronted Amazons

(*Amazon albifrons*), Puerto Rican Parrots (*Amazon vittata*), Short-Billed White-Tailed Black Cockatoos (*Calyptorhynchus funereus latirostris*), Indigo Macaws (*Anodorhynchus leari*), corvids, (crows) Florida Scrub Jays (*Apelocoma coerulescens coerulescens*) and even chickens (*Gallus gallus*) use vocal calls to categorize predators in order to alert other group members (Pepperberg 2001). Thus both cognitive capacity and communication skills are apparent in birds. These skills are likely to direct not only learning in birds but also what is appropriate to learn (Pepperberg 2001).

There is strong evidence that birds are capable of social learning. In young captive Keas (*Nestor notabilis*), exploration and manipulation of a food container improved after observation of an experienced group member (Huber et al 2001). In controlled experiments, wild caught European Blackbirds (*Turdus merula*) learned and demonstrated antipredator behavior from other model birds exhibiting antipredator behavior. Additional findings from these trials were that the visualization of the teacher bird could not be effectively replaced by taped antipredator calls alone. Further, the strength of response by the teaching bird did not affect the responses of the learner birds; all subsequent responses were strong (Curio 1988). Learner birds effectively transmitted this information by becoming teacher birds through six series of birds progressing from learner to teacher (Curio 1988). Lastly, birds exhibited a preparedness to learn; being more likely to evidence antipredator behavior directed toward biologically

relevant stimuli (snakes, other birds) than other stimuli such as a similarly sized bottle (Curio 1988; Curio 1998).

Antipredator Conditioning in Avian Reintroduction Programs

Early work exposing the captive Masked Bobwhite Quail (*Colinus virginianus ridgwayi*) to humans, dogs and hawks improved predator avoidance skills such as cover seeking, and covey coordination. These quail had higher survival rates than previously released (inexperienced) quail (Ellis et al 1977).

The feasibility, success, and applicability of antipredator conditioning in birds has been addressed in a study of New Zealand Robins (*Petroica australis*), a nonendangered species. Young robins learned to fear a taxidermic predator model after training both in the wild and in prerelease conditions. Findings of this study suggest that training birds for predator recognition is cheap, simple, and quick to apply and should be incorporated in reintroduction programs of endangered species. However, only the exhibition of antipredator behavior (guard calls, avoidance of the predator) by the exposed robins was used to measure the success of this training. Survival after release and reproduction sufficient to maintain a stable population are considered the ultimate measures of any antipredator conditioning program but were not assessed in this study.

In prerelease conditioning of Houbara Bustards (*Chlamydotis [undulata] macqueenii*), survival of birds significantly increased after exposure to a live predator as compared to birds exposed to a taxidermic predator (Heezik et al 1999). Measures of predator aversion behavior in these birds prior to release

were not indicators of survival after release. Thus exhibition of antipredator behavioral changes alone may not equal survival upon reintroduction.

In prerelease conditioning of the Takahe, exposure to different types of model was employed in an attempt to instill predatory recognition as well as get birds to assume an aggressive or attack posture toward the predator model. Takahe chicks were not only attacked by stoat models at both close and far range but also watched a model Takahe being attacked and apparently killed by a model stoat. Increased vigilance, determined by the distance birds maintained from the stoat, was achieved but actual attacking of the predator (by the observer Takahe) was only noted in a brief instance. Further, whether these sessions ultimately increase survival was not examined (Holzer et al 1996).

While training prior to reintroduction of captive-bred animals can improve antipredator behavior, it has been suggested that some animals are more likely to have positive results in response to antipredator conditioning (Griffin et al 2000). Animals which are more likely to be amenable to antipredator conditioning include those that have only experienced ontogenic isolation rather than evolutionary isolation from predators, animals which have been isolated from some but not all predators, and animals with innate "species specific defense reactions" which are appropriate to the predator to be avoided (Griffin et al 2000). Antipredator conditioning may only enhance preexisting antipredator behaviors. Antipredator conditioning may also risk emergence of inappropriate behaviors during conditioning. Antipredator behaviors appear innate in

Mississippi Sandhill Cranes, and complete predatory exclusion has never occurred in this mainland population. Further, reintroduced cranes have experienced a lack of predation within their lifetime, or not more than two crane lifetimes, as their parents were removed from the wild in the egg presumably without predator exposure. Thus it appears that the Mississippi Sandhill Crane is, as judged by the above criteria, a promising candidate for antipredator conditioning.

Our study of antipredator conditioning of cranes differs from previous reintroduction conditioning programs. In population biology, animals are classified in terms of r-selection and k-selection, where r-selection refers the animals intrinsic ability to achieve maximal population density and k-selection refers to the carrying capacity of the animal (Pianka 1970). R-selected animals tend to reproduce more quickly and with more fecundity, whereas k-selected animal tend live longer but are less fecund. Our study is the first, to the authors' knowledge, which involves conditioning a k-selected species in which predation appears to be a limiting factor for populations. Previous conditioning programs have focused on r-selected species subject to predation or k-selected species in which predation was not a limiting factor or the subject of conditioning (Wallace 1994).

MATERIALS AND METHODS

Site Description

This study was approved by the Institutional Animal Care and Use Committee at Louisiana State University as well as the Research Overview Committee of the Audubon Nature Institute.

All experimental treatments were conducted at the Freeport MacMoran Species Survival Center in association with the Audubon Institute Center for Research of Endangered Species located in New Orleans, Louisiana. The center maintains an active breeding flock (15 pairs) of Mississippi Sandhill Cranes (MSHC) adults which have been hatched from eggs collected in the wild. Of these, only a single crane has been released to the wild and recaptured for breeding. Adult pairs are held in nonadjacent covered chain link rectangular pens 45 by 90 feet. Subadults are housed in groups in a similar pen configuration (Figures 1 and 2). As cranes do not view chain link as a complete barrier (Wellington et al 1996), this allowed experimental subjects and models to display a full range of behavioral response, even those requiring proximity. All cranes were individually tagged with external and internal markers.¹

Experimental Subjects

Experimental subjects consisted of Mississippi Sandhill Cranes (*Grus canadensis pulla*) (MSHC) hatched in incubators and housed at the Freeport Macmoran Species Survival Center (FMSSC), where they have little if any

¹ AVID Microchipping System, AVID Canada, Suite 204, 615-11 Avenue SE, Calgary AB, Canada, T2GOYB

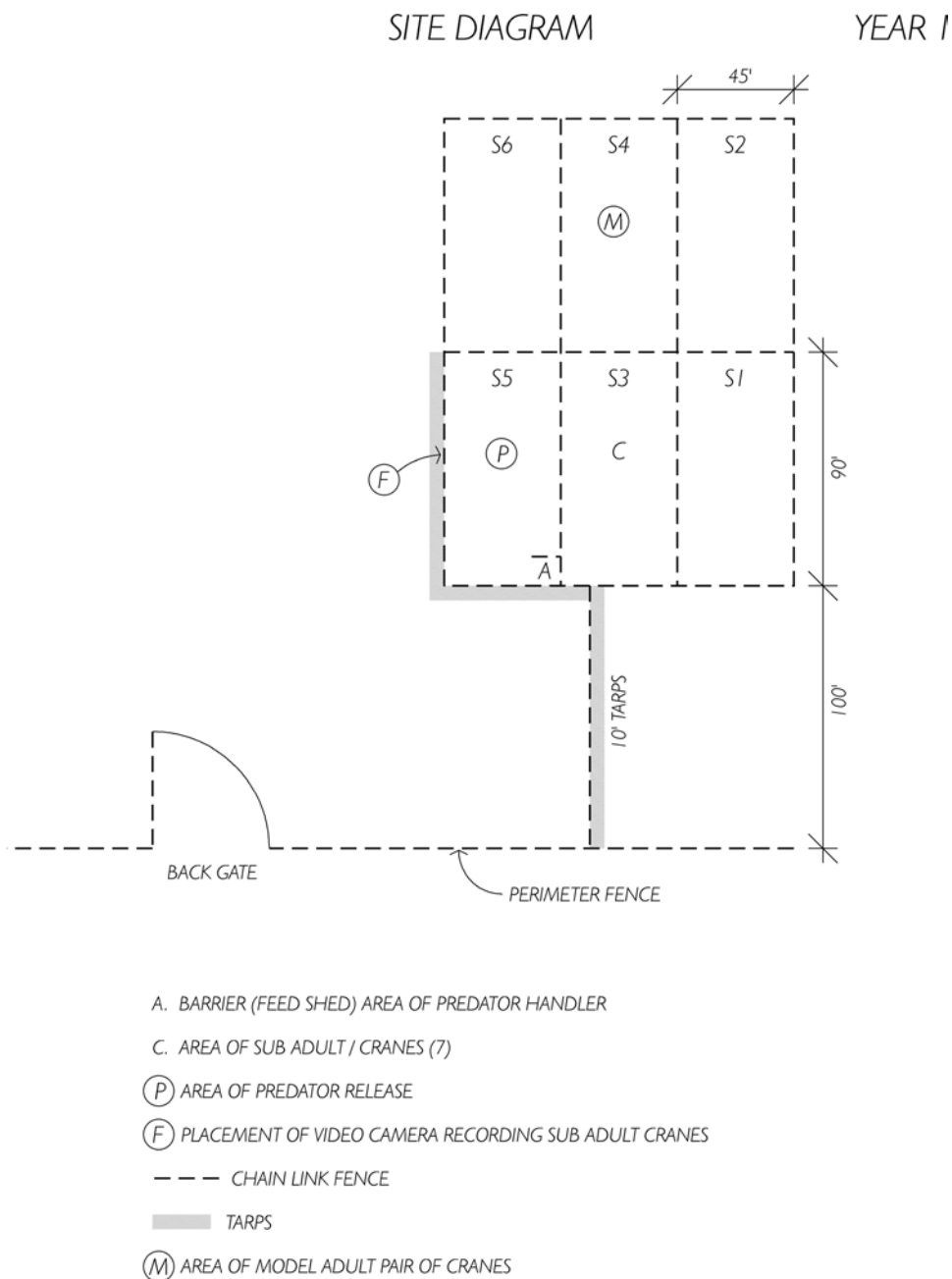


Figure 1. Site Description for Antipredator Conditioning of Subadult Mississippi Sandhill Cranes in Year 1.

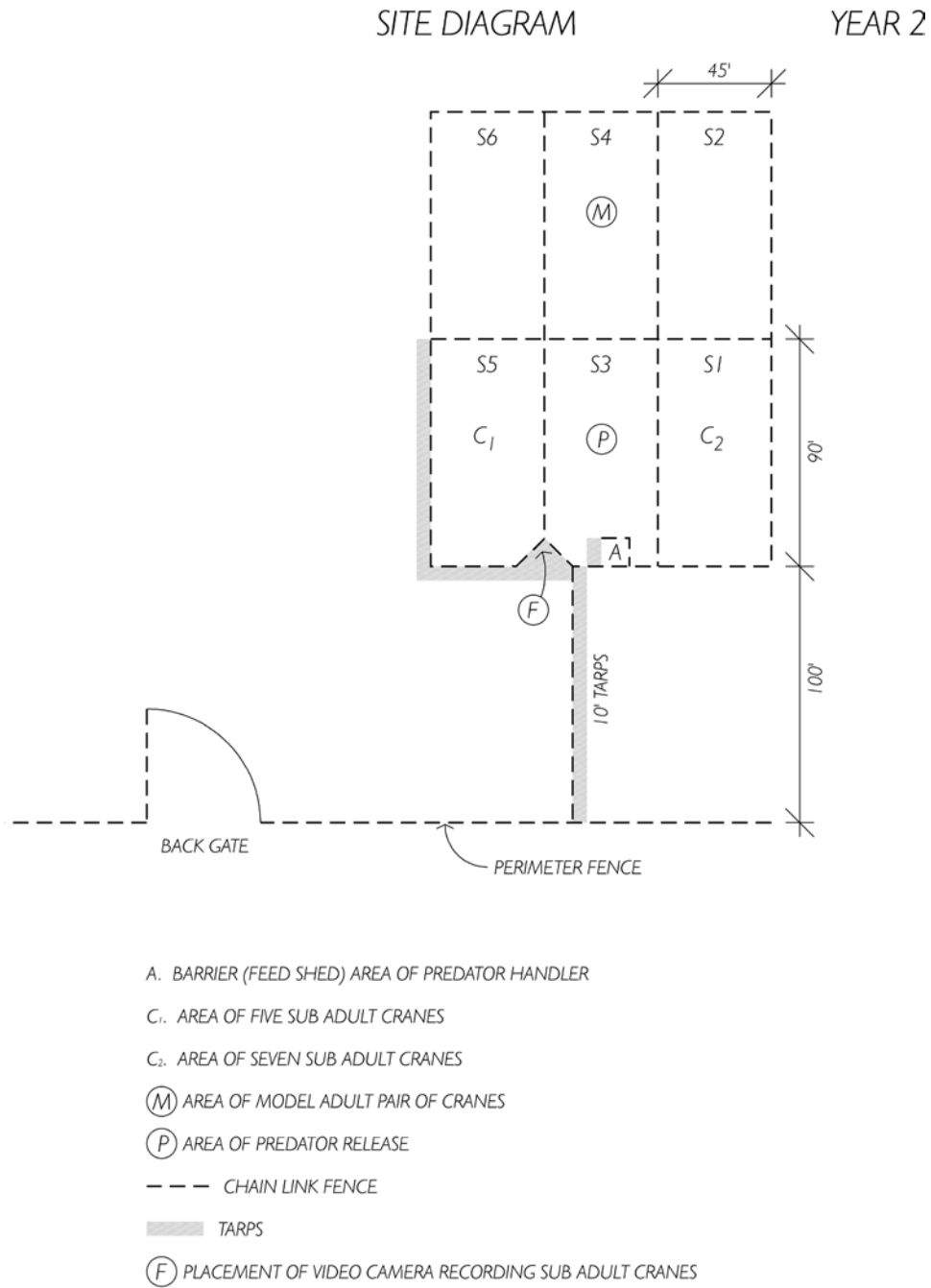


Figure 2. Site Description for Antipredator Conditioning of Subadult Mississippi Sandhill Cranes in Year 2.

exposure to natural predators of cranes due to extensive enclosures. Chicks were conceived by either natural fertilization or by artificial insemination (Table 14, Appendix C) and were reared by the FMSSC staff by a combination of puppet and costume techniques (Ellis et al 2000). Age of subadults at the time of antipredator conditioning, refuge introduction, and final debrailing for release can be determined from Table 14, Appendix C. Human aversion training was performed on all cranes prior to the antipredator conditioning protocol, regardless of whether antipredator conditioning was performed (Nagendran et al 1996).

Model Selection

Initially, a single adult pair of MSHC were chosen as models and then used each successive year in antipredator conditioning of subadults. The model pair was chosen based on past breeding success, and aggression and alertness exhibited toward the staff, as well as appropriate responses when predators were introduced to their vicinity. Unproven natural breeders were preferred to lessen the likelihood of having to move or disturb cranes sitting on eggs for use in antipredator conditioning to pens adjacent to the subadults. A summary of antipredator behavior evidenced by this pair is presented in Table 1 below.

Table 1. Antipredator Behaviors Exhibited By Model Mississippi Sandhill Cranes During Initial Predator Exposure

	Coyote	Bobcat
Model Pair Behaviors	Guard Call	Guard Call
	Run Flap	Unison Call
	Neck Stretch Wing Spread Run	Tall Alert
	Tall Alert	
	Flight	

Identification of Experimental Subjects

Cranes undergoing antipredator conditioning were temporarily marked on the neck feathers and or body feathers with one or more aerosolized antibacterial powders oxytetracycline², furazolidone³, and or methyl violate.⁴ An effort was made to mark cranes at least 48 hours prior to antipredator conditioning but due to water solubility and inclement weather, cranes were sometimes marked on the morning of experimentation.

Antipredator Conditioning

In phase one, experimental subjects undergoing antipredator conditioning were exposed to the predator without the model pair present. This allowed for baseline behavioral measurement of innate antipredator behavior. In phase two experimental subjects were exposed to the predator using the same procedure with the model pair present. Predator exposure occurred only once in both phases of experimentation. Placement of the model pair occurred a minimum of one week prior to predator exposure to allow acclimatization of the subadults to the adults.

Predator Exposure

Subadults behavior was recorded for an average of 4.5 minutes, range (1.1-6.3 minutes) prior to the introduction of the predator, for an average of

² Oxytetracycline, 2%. Terramycin TM aerosol spray (coloured). Pfizer limited, Sandwich, England

³ Aerosol powder, 4%. Veterinary Products Laboratories, PO Box 34820, Pheonix, AZ 85067 USA
©1998

⁴ Wound Kote ®, methyl violate, acriflavin, technical furfural, sodium propionate, urea, glycerine, propylene glycol, isopropyl alcohol 30%, propellants 40%. Farnham companies Inc. Horse Products Division, PO Box 34820, Pheonix Arizona 85067-4820

6.42 minutes (range 4.58-11.0 minutes) after the introduction of the predator and for an average of 15.46 minutes (range 9.09-26.00 minutes) after the removal of the predator. Predators consisted of a live tame bobcat (*Lynx rufus*) and a live tame coyote (*Canis latrans*) (Figure 3 a and b respectively). Predators were introduced into an enclosure adjacent to the subadults and models (when present). In all phases where a predator was present, a failsafe mechanism was employed by radio such that animal caretakers would stop the procedure should crane endangerment occur.

Visual barriers of blue, brown or tan opaque plastic tarps were placed in order to limit crane visual access to the predator or the predator handler prior to predator introduction (Figures 1 and 2). These blinds also allowed observation and recording of subject behavior, without the observer being visualized by cranes. Blinds were placed a minimum of two weeks before experimentation to allow subject acclimatization.

Data Collection

In each phase, crane behaviors appropriate for predator avoidance or antagonism (Table 2) were recorded individually for each bird in the prepredator, predator and postpredator periods. The behavioral response was categorized as a binomial outcome (present or absent), nondurational event. Behaviors were either recorded manually or onto videotape.⁵ Video recordings were later converted to MPEG files for viewing on Windows Media Player.⁶ Audio and video

⁵ Sony® Video Camera Recorder, Model # CCD FX 620, Tokyo, Japan.

⁶ Windows Media Player © 1992-2000 Microsoft corporation, Version 7.00.00.1440.

recordings were then viewed and the behaviors of each individual crane recorded as present or absent during the prepredator, predator and postpredator time periods.



Figure 3a. Bobcat (*Lynx rufus*) Used for Antipredator Conditioning of Subadult Mississippi Sandhill Cranes.



Figure 3b. Coyote (*Canis latrans*) Used for Antipredator Conditioning of Subadult Mississippi Sandhill Cranes.

Table 2. Crane Behaviors Appropriate in Response to Predators

<i>Behavior Type</i>	Agonistic	Nonagonistic
Vocal	Hiss	Preflight Call/ Flight Intention Call Alarm Call Guard Call/ Unison Call Contact Call
Postural	Mobbing Wing Spread Display Crouch Run Flap Bill Stab/ Bill Sparring Jump Rake Wing Thrash	Alert Posture/ Tall alert Preflight Posture/ Neck Stretch Display Bunching Neck-Stretch-Wing-Spread-Run Flight

Release

Subadults were released to the Mississippi Sandhill Crane National Wildlife Refuge in Gautier, Mississippi (Figure 4). Dates and areas of release as well as the age of cranes at release are detailed in Table 1. All subadults were equipped with radio transmitters and banded for identification purposes. A gentle release with debrailing occurred between 13-22 days after introduction to the refuge (Nagendran et al 1996). Birds continue to be monitored in the field by biologists of the Mississippi Sandhill Crane National Wildlife refuge. Mortalities and causes of death of antipredator conditioned and control MSHC to date are detailed in Table 2. A predator control program was already in place at the beginning of the study and the amount of trapping as well as the number of predators caught has varied throughout the study. Rate of trapping, results of this program and crane deaths due to predation per year are shown in Table 3.

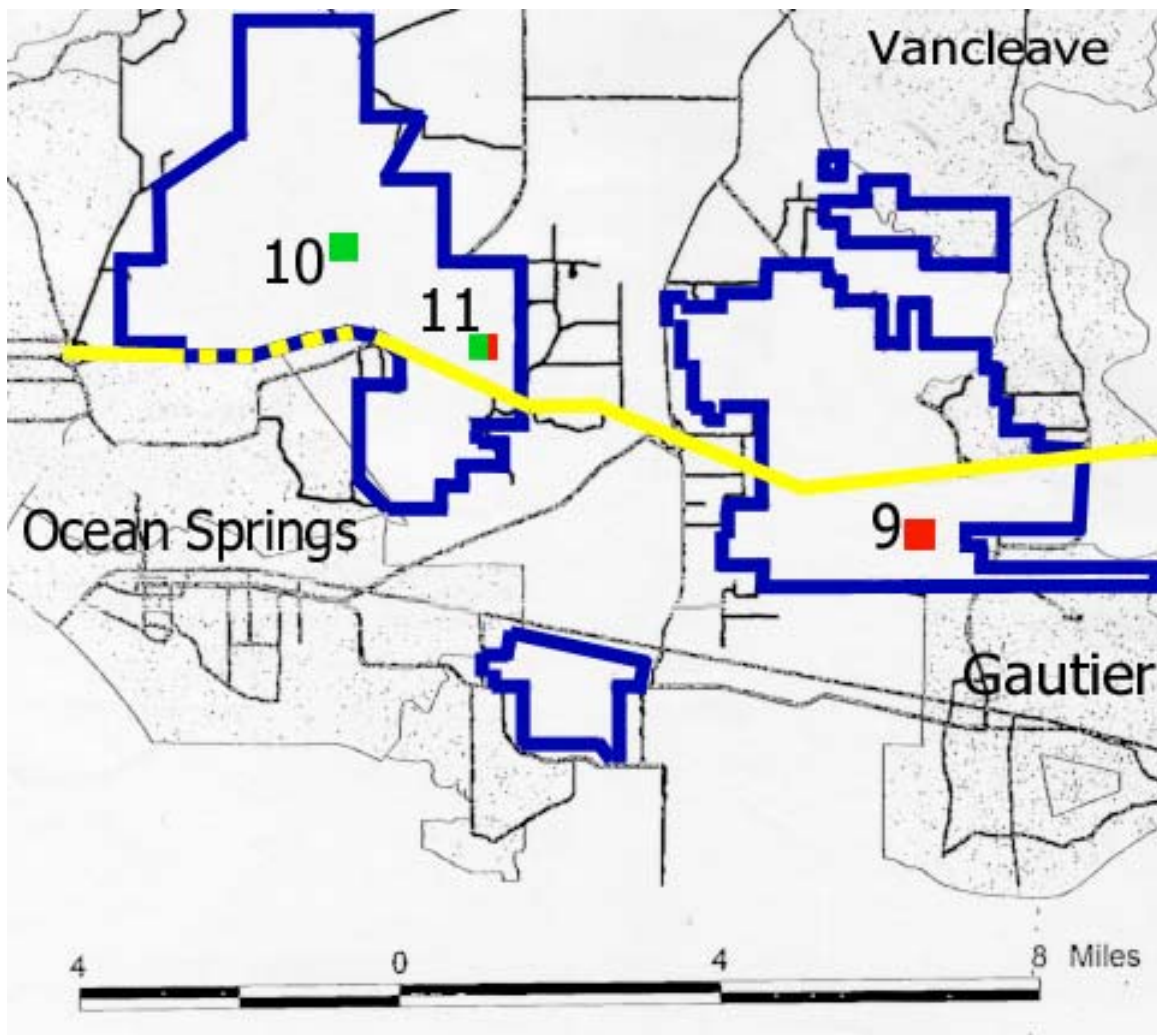


Figure 4. Subadult Mississippi Sandhill Crane Release Sites. All cranes were released in the Mississippi Sandhill Crane National Wildlife Refuge, Gautier, Mississippi. Interstate Highway I-10 is denoted by yellow. Blue outlines the boundaries of the refuge. Green denotes areas where antipredator conditioned cranes were released and red denotes areas where nonantipredator conditioned (control) cranes were released.

Table 3. Summary of the Predator Control Program at the Mississippi Sandhill Crane National Wildlife Refuge (Hereford 2002).

Year	Trap-Nights	Large Predators Caught (Not including Dogs)	Crane Deaths Due to Predation
1994	3872	34	1
1995	2878	27	3
1996	1886	11	12 (includes 10 predated in pens)
1997	3660	42	1
1998	879	5	4
1999	1944	48	12
2000	3811	60	4
2001	7353	99	0

Table 4. Summary of Data Collected

	Behavioral Phase	Release Phase
Experimental Unit	subadult MS Cranes	subadult MS Cranes
Sampling Unit	subadult MS Cranes, post antipredator training	subadult MS Cranes, post release
Measurement Unit	antipredator behaviors in presence of predator (See Table 1)	mortality due to predators (subadult postrelease MS Cranes)
Variable Measured	behavioral response pre, during and post antipredator conditioning	survival of antipredator conditioned subadult MS Cranes post release

Statistical Analysis

Behavioral data were collected during antipredator conditioning trials from 12 cranes in cohorts of 5 and 7 in two different years. An additional 7 cranes in year 2 also underwent antipredator conditioning however no behavioral data was collected from these cranes.

The presence of specific behaviors was modeled using logistic regression to determine and quantify any association of age group (≤ 299 or >299 days) at the time of antipredator conditioning, gender, group (year one or year two), phase of conditioning (prepredator, predator, post predator), model presence, or type of predator (bobcat or coyote) with behavioral responses. The degree of association was expressed by the point estimate and its 95% confidence interval of the odds ratio which excluded 1.0 was considered significant. PROC LOGISTIC⁷ was used for the analysis. Few agonistic behaviors were observed, thus these were grouped as a single behavior for statistical purposes.

⁷ SAS Version 8.0, SAS Institute, Cary North Carolina

RESULTS

In no phase of this experimental protocol were the models or experimental subjects harmed. This is in contrast to previous human aversion protocols at the same facility in which one crane has died secondary to escape attempts.

Release Phase

Because of the low number of subadult crane mortalities after reintroduction to the refuge since the inception of this program, no statistical analysis of mortality was performed. Causes and dates of subadult crane mortality in this study are listed in Appendix C, Table 14.

Behavioral Phase

All behaviors observed that were considered appropriate in the presence of predators (Table 2) are tabulated in Appendix B. Behaviors observed in the subadult cranes were predominantly nonagonistic or flight behaviors. Nonagonistic display behaviors observed were limited to the tall alert, the preflight posture, neck-stretch-wing-spread-run and flight. Vocalizations observed were limited to the contact call and the guard call and one call of uncertain identity. It is doubtful if a hiss had occurred, that the observer would have been able to hear it due to the distance from the birds. Agonistic behaviors were only noted in the post predator phase, and these behaviors were invariably directed at conspecifics. Agonistic behaviors observed included 3 bill stabs and 1 run flap. No significant effect of sex or type of predator were found on the behavior of the subadult cranes observed in antipredator conditioning trials of

this study. The frequency of selected subadult crane behaviors in response to antipredator conditioning are represented in Table 5.

Table 5. Frequencies of Appropriate Behaviors of Subadult Mississippi Sandhill Cranes Undergoing Antipredator Conditioning

Behavior	Prepredator Phase		Predator Phase		Postpredator Phase	
Contact Call	.47	.58	.18	.46	.59	.46
Guard Call	0	0	.12	.38	.29	.04
Tall Alert	.12	.75	.41	.96	.53	.88

Grey backgrounds denote model presence.

17 behavioral observations were without the model present for each behavior.

24 behavioral observations were made with the model present for each behavior.

There was a significant association of model presence and antipredator conditioning phase with the presence of the behavior of tall alert. Accounting for the antipredator phase of examination, the odds of this behavior occurring were 15.4 times more likely if the model was present (95% CI 5.6-41.7). When accounting for model presence, the odds of the occurrence of the tall alert behavior were 4.8 times more likely in the post predator period than in the prepredator period (95% CI 1.5-15.6) and 4.8 times more likely in the predator period than in the prepredator period (95% CI 1.5-15.6).

Vocal behaviors, when grouped together, were significantly associated with the group of birds and the antipredator conditioning phase. Accounting for the effect of antipredator conditioning phase, the odds of vocal behavior occurring were 29.4 times more likely in the second group tested than in the first (95% CI 10.2-83.3). Accounting for the affect of group, the odds of vocal behavior occurring were 4.1 times more likely in the prepredator period than in

the predator period (95% CI 1.2-14.2). There was a significant association of older birds (birds aged greater than 299 days) with the occurrence of guard calling. Odds of the occurrence of this behavior were 16.6 times more likely in the older age group of birds than in the younger age group of birds (95% CI 3.6-76.9). There was a significant association of group and of phase of antipredator conditioning with the occurrence of contact calling. Accounting for the phase of antipredator conditioning, the odds of seeing this behavior were 29.4 times more likely in the first year than in the second year (95% CI 10.2-83.3). Accounting for the group, the odds of seeing this behavior were 4.1 times more likely in the prepredator period than in the predator period (95% CI 1.06-15.2)

Lastly, there was also significant association of group and the presence of flight. Accounting for the period of examination, the odds of seeing this behavior was 4.0 times more likely in the second year than in the first (95% CI 1.06-15.2).

DISCUSSION

Comparison of Avian Antipredator Conditioning Methods

In devising methods used in our antipredator conditioning program of Mississippi Sandhill Cranes multiple factors were reviewed. Habituation to the predator was of primary concern. In Houbara Bustards, behavior indicative of habituation to predatory presence was observed as early as the third training session of only a one minute duration (Heezik et al 1999). Reported predator exposure times of other avian antipredator conditioning programs vary from 40 seconds to 40 minutes with the number of exposures varying from one to ten days (Holzer et al 1996, Heezik et al 1999, McLean et al 1999). Our choice of a 5 minute exposure time and two exposures facilitated testing the necessity of adult model bird presence while minimizing the chances of habituation. We feel confident that habituation to predator presence did not occur in our study because all birds showed alert behavior both during and after predator exposure.

While use of a live predator in direct contact with trainee birds has been shown to increase the risk of injury to birds, use of live predators in antipredator conditioning has also been associated with increased survival of released birds (Heezik et al 1999). We feel our compromise of protected contact exposure of the cranes to live predators was better than use of a taxidermic predator model because birds were exposed to predator locomotion, sounds and behavior which would have been difficult to artificially recreate. In addition exposure to predator odor may also have been of benefit as recent investigations support the theory

that avian olfaction may function in predator detection (Fluck et al 1996; Jones et al 1997).

Factors Affecting Subadult Mississippi Sandhill Crane Behavior During Antipredator Conditioning

In wild Sandhill Cranes, an increased frequency of alert behavior was associated with juveniles without parents, adult males rather than adult females, and adults in pairs or families (Tacha 1981). Adults were more likely to be alert than juveniles, cranes alerted more in April or May, or when in nesting grounds or when flocks were feeding as compared to resting (Tacha 1981). Cranes in flocks of one to three birds tended to alert more than cranes in larger flocks (Tacha 1981). In our study group size was not very different and all groups included more than three cranes, correspondingly no group differences of the tall alert behavior were found. The tall alert behavior was not significantly associated with sex or age although all cranes were relatively similar in age (Table 14, Appendix C). Temporal measurements to quantify the time spent alert throughout or in certain phases of antipredator conditioning were beyond the scope of this study. However such measurements might have provided a more sensitive measure of overall alertness and therefore might have been more likely to differentiate subtleties expected in alert behavior due to age or sex. The presence of model adult cranes positively affected the occurrence presence of the tall alert behavior in subadult cranes suggesting that the presence of a model may be useful in creating increased vigilance in subadult cranes.

Vocalizations were not affected by the presence of a model adult cranes. However subadult crane vocalizations were considered appropriate in predatory presence. Innate antipredator mechanisms of many birds involve decreased vocalization or silence in order to avoid predation. Both the behaviors of contact calling and vocalization, in general, occurred more frequently in the prepredator time period than in the predator time period of antipredator conditioning suggesting that the goal of social reinstatement was lessened by predator presence. This also suggests that the lessening of vocal behavior in response to a novel stimulus may be either innate or already learned and not subject to change through social learning as it was not affected by age nor was it affected by model presence. Contact calling significantly decreased with age. This same phenomenon has also been documented in the domestic fowl (Suarez and Gallup 1983).

The type of predator had no apparent effect on the behaviors of the subadult cranes. However this is not unexpected as avian behaviors will often differentiate predator type by grouping according to predatory strategy (flying or ground) rather than vertebrate phyla (bird, reptile, mammals). Many species, including western American crows as well as domestic chickens, appear to be able to discriminate between predators or at least predator types (location or type of attack rather than mammal bird or reptile) by varying their antipredator behavior (Kruuk 1964; Buitron ; Walters 1990; Jacobsen and Ugelvick 1992; Evans et al 1993; Hauser and Caffrey 1994; Winkler 1994; Arroyo et al 2001).

Both of the predators used on our study were of the same phylogenetic class (mammals) and have similar ground based predatory tactics.

The finding of an absence of agonistic behaviors in subadult cranes toward predators was expected. Model adult cranes did not evidence agonistic behaviors toward predators during their initial exposure to the predators or in any antipredator conditioning trial. Further while agonistic behavior has been observed in adult cranes in the wild in response to predators, observation of agonistic behavior of subadult cranes in the wild has rarely been documented and has invariably been directed at conspecifics of similar age rather than predators (Voss 1976).

An interesting finding of this study was that guard calling did not occur during antipredator conditioning in Mississippi Sandhill Cranes less than 299 days old. This was despite conspecific guard calls in adjacent pens. This is in contrast to previous documentation of the development of this call in captive Greater Sandhill Cranes at 9-10 weeks of age, much younger than any of the cranes observed in our study (Voss 1977).

Other Factors Affecting Mississippi Sandhill Crane Antipredator Behavior

The effect of diurnal, or seasonal variation on responses of juvenile MSHC during antipredator conditioning were not evaluated in this study. Moreover, the effect, if any, of critical learning periods on the success of antipredator conditioning has not been assessed. In owls, studies have shown that early learning can allow for adaptation in later life (Knudsen 1998). Similar adaptation

cannot be achieved in owls without prior early learning experience. In subadult cranes, periods of increased behavioral attachment to adults occur in the first two weeks of age, at fledging (11-14 weeks) and just before and during migration (Horwich 1996). Theoretically it would be best to antipredator condition juvenile crane at ages when they are most likely to be exhibiting strong social attachment behavior toward adults, hopefully resulting in an increase in appropriate antipredator behaviors observed and copied from adults. However, conditioning at this age may be difficult as these time periods may be far removed from the age at which birds are released. Lastly, although controlling time of year and even time of day that antipredator conditioning was performed were attempted in this study, these factors were inconsistent and logistically unattainable goals.

Full assessment of this antipredator conditioning program as measured by survival, successful pair bonding, reproductive success and subsequent survival of progeny has yet to be performed. Five years or more may be necessary to adequately assess the effectiveness of the antipredator conditioning program since pair bonding and nesting in Sandhill Cranes normally begins at 2-5 years of age (Archibald and Lewis 1996). Hand-reared birds may be less likely to choose appropriate nesting sites, and may nest later than wild-reared conspecifics (Page et al 1989). However increased vigilant behavior, as found in this study in the presence of conspecifics, has been associated with earlier pair bonding in other species (Beani and Dessi-Fulgheri 1998).

Genetic diversity, genetic attributes, or the lineage of reintroduced cranes were not investigated in our study. While it is generally believed that lack of genetic diversity may have deleterious consequences for this population, this concept has yet to be proven in avian populations (Harmon and Bussche 2000). Methods of measurement and maintenance of genetic diversity are controversial. Options for measuring genetic diversity include DNA fingerprinting to evaluate similarity, heterozygosity and allelic diversity of groups and allozyme electrophoresis to determine genetic loci, alleles and heterozygosity (Haig et al 1990; Dessauer et al 1992; Harmon and Bussche 2000). Options for choosing breeding pairs to maintain genetic diversity include prioritization of genetic diversity, maintenance of rare alleles, conservation the founding gene pool of a population, maximizing allelic diversity, random pairings, or pairing based in fecundity (reproductive fitness) (Haig et al 1990). While the original population of MSHC has been evaluated for genetic diversity via electrophoresis of allozymes, it would be of value to trace the lineage of released offspring and to assess the genetic variability of released cranes to determine the effect, if any, of genetic diversity or genetic makeup on the reintroduction potential of MSHC (Dessauer et al 1992). In addition, determination of genetic makeup of cranes which showed appropriate behavior, or reproductive viability in the wild may be useful in future reintroductions, especially when breeding can be controlled by artificial insemination. Conservation of behavioral diversity has also been suggested as a goal (Sutherland 1998). It should be noted that in the short time

in which behavior of each group of birds was documented for our antipredator conditioning trials, a full complement of nonagonistic behaviors useful in averting predators were observed in each group.

SUMMARY AND CONCLUSIONS

Summary

Mississippi Sandhill Cranes (*Grus canadensis pulla*) are critically endangered and crane numbers in the wild are low enough to be severely affected by factors which would normally have little effect on an avian population. Population size of these cranes may have been relatively small for an extended period of time resulting in reduced genetic diversity which may further adversely affect population growth. While human related factors such as land development and hunting have probably had the greatest effect on the population, current numbers of birds are at a low ebb allowing additional factors such as disease and predation to have significant effect on population size. Despite coordinated captive breeding and reintroduction efforts, as well as predator control programs, the major cause of known death of juvenile Mississippi Sandhill Cranes remains predation.

Unfortunately, captive-bred birds may not maintain the skills necessary for predator recognition or evasion. Avian cognition and learning abilities have been documented in many species. Birds, such as cranes, which retain an evolutionary behavioral makeup including innate predatory evasion skills appear best suited to antipredator conditioning. In this study, exposure of subadult juvenile cranes to two mammalian predators with and without the presence adult cranes was performed in order to assess the necessity of the presence of adult cranes on behaviors of subadult crane undergoing antipredator conditioning programs.

Subadult cranes which were and were not exposed to predators were then reintroduced to the refuge and mortality data was compiled.

Conclusions

Observations of behavior in captivity showed that vigilant behavior was significantly affected by the presence of adult cranes during antipredator conditioning trials. Vocalizations were appropriately affected by the presence of the predator, whether adult cranes were present or not, suggesting either that these behaviors are innate or that a critical learning period for these behaviors had already occurred. While death in juvenile Mississippi Sandhill Cranes due to predation has not occurred since the inception of our program, these results may be affected by weather or climatic conditions of the year of release, or an increase of predator control which was started in the same year as the antipredator conditioning program. The effects of diurnal, seasonal variation in antipredator behavior, behavioral attachment periods of juvenile cranes, genetic diversity, or lineage on behavior or mortality of released juvenile Mississippi Sandhill Cranes remain unknown. The full effect of antipredator conditioning on survival to pair-bonding, reproductive success, rearing of offspring, and survival of offspring of cranes that have undergone antipredator conditioning has yet to be assessed. This assessment is ongoing and may take greater than 5 years.

REFERENCES

- Allen, R (1952). The Whooping Crane, Research Report No. 3. New York, National Audubon Society: 157.
- Altmann, M (1960). "Moose Runs From a Sandhill Crane." Journal of Mammology **41**: 525.
- Archibald, G, J Lewis (1996). Crane Biology. Cranes: Their Biology Husbandry and Conservation. D Ellis, GF Gee, CM Mirande. Washington, D.C., Department of The Interior, National Biological Service, USA: 1-30.
- Ardern, SL, IG McLean, S Anderson, R Maloney, DL Lambert (1994). "The Effects of Blood Sampling on the Behavior and Survival of the Endangered Chatham Island Black Robin (*Petroica traversi*)."
Conservation Biology **8**: 857-862.
- Armstrong, DP, JG Ewen (2001). "Assessing the value of follow-up translocations: a case study using New Zealand robins." Biological Conservation **101**: 239-247.
- Arroyo, B, F Mougeot, V Bretagnolle (2001). "Colonial breeding and nest defence in Montagu's harrier (*Circus pygargus*)."
Behavioral Ecology and Sociobiology **50**: 109-115.
- Beani, L, F Dessi-Fulgheri (1998). "Anti-predator behaviour of captive Grey partridges (*Perdix perdix*)."
Ethology, Ecology & Evolution **10**: 185-196.
- Beauchamp, G, B Livoreil (1997). "The effect of group size on vigilance and feeding rate in spice finches (*Lonchura punctulata*)."
Canadian Journal of Zoology **75**: 1526-1531.
- Borchelt, PL, SC Ratner (1973). "Development of freezing and immobility, predator defenses, in the Bobwhite quail (*Colinus virginianus*)."
Behavioral Biology **8**: 83-92.
- Buitron, D (1983). "Variability in the responses of black-billed magpies to natural predators." Behaviour **88**: 209-236.
- Bunin, J, I Jamieson (1996). "Responses to a Model Predator of New Zealand's Endangered Takahe and Its Closest Relative, the Pukeko." Conservation Biology **10**: 1463-1466.

- Bunin, JS, IG Jamieson (1995). "New approaches toward a better understanding of the decline of the Takahe (*Porphyrio mantelli*) in New Zealand." Conservation Biology **9**: 100-106.
- Caro, T (1999). "The behavior conservation interface." Trends in Ecology and Evolution **14**: 366-369.
- Cemmick, D, D Veitch (1987). The Kakapo Breeding System. Kakapo country: the story of the world's most unusual bird. London, Hodder and Stoughton: 75-88.
- Chandler, CR, RK Rose (1988). "Comparative Analysis of the Effects of Visual and Auditory Stimuli on Avian Mobbing Behavior." Journal of Field Ornithology **59**: 269-277.
- Collar, N, A Juniper (1992). Dimensions and causes of the parrot conservation crisis. New World Parrots in Crisis: Solutions from Conservation Biology. S. Beissinger, Noel R F Snyder. Washington, Smithsonian Institution Press: 1-24.
- Conover, MR (1987). "Acquisition of Predator Information by Active and Passive Mobbers in Ring-Billed Gull Colonies." Behavior **102**: 41-57.
- Cote, IM, WJ Sutherland (1997). "The effectiveness of removing predators to protect bird populations." Conservation Biology **11**: 395-405.
- Cresswell, W (1994). "Flocking is an effective anti-predation strategy in redshanks." Animal Behavior **47**: 433-442.
- Curio, E (1988). Cultural Transmission of enemy recognition by birds. Social Learning: psychological and biological perspectives. Zentall, TR, BG Galef, Jr. Hillsdale, New Jersey, Lawrence Earlbaum and Associates: 75-97.
- Curio, E (1998). Behavior as a tool for management intervention for birds. Behavioral Ecology and Conservation Biology. T. M. Caro. New York, Oxford University Press: 163-187.
- Derrickson, S, J Carpenter (1980). Ethology and Management of Captive Sandhill Cranes. American Association of Zoo Veterinarians, Washington, D.C.: 76-81.
- Derrickson, S, J Carpenter (1983). Behavioral Management of Captive Cranes - Factors Influencing Propagation and Reintroduction. Archibald, GW, RF

- Pasquier. Proceedings of the International Crane Workshop, Bharatpur, India, International Crane Foundation: 493-511.
- Dessauer, H, G Gee, J Rogers (1992). "Allozyme evidence for crane systematics and polymorphisms within populations of Sandhill, Sarus, Siberian and Whooping cranes." Molecular Phylogenetics and Evolution **1**: 279-88.
- Dickson, JG (1995). Return of Wild Turkeys. Our living resources: A report to the nation on the distribution, abundance, and health of US plants, animals, and ecosystems. LaRoe, E, G Farris, C Puckett, P Doran, M Mac. Washington, DC, National Biological Service: <http://biology.usgs.gov/s+t/noframe/b028.htm>.
- Ellis, DH, SJ Dobrott, JG Goodwin, Jr. (1977). Reintroduction Techniques for Masked Bobwhites. Endangered Birds: Management Techniques for Preserving Threatened Species. S. Temple. Madison, The University of Wisconsin Press: 345-354.
- Ellis, D, S Swengel, G Archibald, C Kepler (1998). "A sociogram for cranes of the world." Behavioural Processes **43**: 125-151.
- Ellis, D, G Gee, S Hereford, T Chisolm, J Nicolich, K Sullivan, N Thomas, M Nagendran, J Hatfield (2000). "Post-release survival of hand-reared and parent-reared Mississippi Sandhill cranes." The Condor **102**: 104-112.
- Evans, CS, L Evans, P Marler (1993). "On the meaning of alarm calls: functional reference in an avian vocal system." Animal Behavior **46**: 23-38.
- Fluck, E, S Hogg, PS Mabbutt, SE File (1996) "Behavioral and Neurochemical Responses of Male and Female Chicks to Cat Odour." Pharmacology Biochemistry and Behaviour **54**: 85-91.
- Gee, GF, SG Hereford (1995). Mississippi Sandhill Cranes. Our living resources: a report to the nation on the distribution, abundance, and health of US plants, animals, and ecosystems. E LaRoe, G Farris, C Puckett, P Doran, M. Mac. Washington, DC, National Biological Service: <http://biology.usgs.gov/s+t/noframe/b157.htm>.
- Gee, GF (2002). Personal Communication - Antipredator Conditioning Project. Patuxent Environmental Research Center, Patuxent Maryland.
- Goth, A (2001). "Innate predator-recognition in Australian brush-turkey (*Alectura lathami*, megapodidae) hatchlings." Behaviour **138**: 117-136.

- Green, R (1997). "The influence of numbers released on the outcome of attempts to introduce exotic birds species to New Zealand." Journal of Animal Ecology **66**: 25-35.
- Griffin, AS, DT Blumenstein, CS Evans (2000). "Training captive-bred or translocated animals to avoid predators." Conservation Biology **14**: 1317-1326.
- Haig, SM, JD Ballou, SR Derrickson (1990). "Management Options for Preserving Genetic Diversity." Conservation Biology **4**: 290-300.
- Harmon, SA, RA Van Der Bussche (2000). "Genetic Attributes of a declining population of reintroduced eastern wild turkeys (*Meleagris gallapavo silvestris*)." The Southwestern Naturalist **45**: 258-266.
- Hauser, MD, C Caffrey (1994). "Anti-predator response to raptor calls in wild crows, *Corvus brachyrhynchos hesperis*." Animal Behavior **48**: 1469-1471.
- Heezik, Y, P Seddon, R Maloney (1999). "Helping reintroduced houbara bustards avoid predation: effective anti-predator training and the predictive value of pre-release behavior." Animal Conservation **2**: 155-163.
- Hereford, SG (2002). Personal Communication - Mississippi Sandhill Crane Mortalities. Mississippi Sandhill Crane National Wildlife Refuge, Gautier, Mississippi.
- Hill, WL, TM Fleming, EM Shrier (1994). "Tonic immobility and high-intensity calls in a precocial chick as a function of age, diet, and time of day." Developmental Psychobiology **27**: 331-342.
- Holzer, C, H-H Bergmann, I McLean (1996). Training Captive-Raised, Naive Birds to Recognise their Predator. Research and Captive Propagation. U Ganslosser, JK Hodges, W Kaumanns.
- Horwich, R (1987). "Behavioral Development in the Red Crowned Crane (*Grus japonensis*)." Zoo Biology **6**: 379 - 389.
- Horwich, RH (1996). Imprinting, Attachment and Behavioral Development in Cranes. Cranes: Their Biology, Husbandry, and Conservation. DH Ellis, GF Gee, CM Mirande, CH Ellis, LA Shaull. Washington, DC, Department of the Interior: 117-119.

- Huber, L, S Rechberger, M Taborsky (2001). "Social Learning affects object exploration and manipulation in keas, *Nestor notabilis*." Animal Behavior **62**: 945-954.
- Jacobsen, OW, M Ugelvik (1992). "Antipredator Behavior of Breeding eurasian widgeon." Journal of Field Ornithology **63**: 324-330.
- Johnsgard, PA (1998). The Sandhill Crane: A Historical Introduction to the Sandhill Crane. Crane Music: A Natural History of North American Cranes. Lincoln, University of Nebraska Press: 31-64.
- Jones, RB, TR Roper (1997). "Olfaction in the Domestic Fowl: A Critical Review." Physiology and Behavior **62**: 1009-1018.
- Jullian, M, J Clobert (2000). "The survival value of flocking in neotropical birds: reality or fiction?" Ecology **81**: 3416-3430.
- Kleindorfer, SHH, B Fessl (1996). "Alarm calls and chick reactions in the moustached warbler, *Acrocephalus melanopogon*." Animal Behavior **51**: 1199-1206.
- Knudsen, EI (1998). "Capacity for Plasticity in the Adult Owl Auditory System Expanded by Juvenile Experience." Science **279**: 1531-1533.
- Koivula, K, A Ronka (1998). "Habitat Deterioration and efficiency of antipredator strategy in a meadow breeding wader, Temminck's stint (*Calidris temminckii*)." Oecologia **116**: 348-355.
- Krams, I (1998). "Dominance-specific vigilance in the Great Tit." Journal of Avian Biology **29**: 55-60.
- Kruuk, H (1964). "Predators and antipredator behavior of the black headed gull." Behaviour **11**: 1-129.
- Kuehler, CMK, JE Kuhn, A Leiberman, N Harvey, B Rideout (1996). "Artificial Incubation, Hand-Rearing, Behavior and Release of common Amakihi (*Hemignathus virens virens*): surrogate Research for Restoration of Endangered Hawaiian Forest Birds." Zoo Biology **15**: 541-553.
- Layne, J (1981). "Nesting, Development of the Young and, Parental Behavior of a pair of Florida Sandhill Cranes." Florida Field Naturalist **9**: 51-75.

- Leberg, P (1993). "Strategies for population reitroduction: effects of genetic variability on population growth and size." Conservation Biology **7**: 194-199.
- Lewis, TE (1996). Special Techniques, Part F: Predator and Pest Management. Cranes: Their Biology Husbandry and Conservation. D Ellis, GF Gee, CM Mirande. Washington, D.C., Department of The Interior, National Biological Service, USA: 245-251.
- Lima, SL, LM Dill (1990). "Behavioral decisions made under the risk of predation: a review and prospectus." Canadian Journal of Zoology **69**: 619-640.
- Lima, S (1993). "Ecological and Evolutionary Perspectives on Escape from Predatory Attack: A Survey of North American Birds." The Wilson Bulletin **105**: 1-47.
- Lima, S (1998). "Stress and decision making under the risk of predation: recent developments from behavioral, reproductve, and ecological prespectives." Advances in the Study of Behavior **27**: 215-290.
- Lima, SL (1998). "Nonlethal effects in the ecology of predator-prey interactions." BioScience **48**: 25-34.
- Lima, SL, PA Bednekoff (1999). "Back to the basics of antipredatory vigilance: can nonvigilant animals detect attack?" Animal Behaviour **58**: 537-543.
- Lima, SL, PA Zollner, PA Bednekoff (1999). "Predation, scramble competition, and the vigilance group size effect in dark-eyed juncos (*Junco hyemalis*)." Behavioral Ecology and Sociobiology **46**: 110-116.
- Littlefield, C (1975). Productivity of Greater Sandhill Cranes on Malheur National Wildlife Refuge Oregon. JC Lewis. Proceedings of the International Crane Workshop, Baraboo, Wisconsin, Oklahoma State University Publishing and Printing: 86-92.
- Macmillan, B (1990). "Attempts to Reestablish Wekas, Brown Kiwis and Red-crowned Parakeets to Waitakere ranges." Notornis **37**: 45-51.
- Maretsky, VJ, NF Snyder, SR Beissinger, DA Clendenen , JW Wiley (2000). "Demography of the California Condor: Implications for Reestablishment." Conservation Biology **14**: 957-967.

- Martella, M, D Renison, J Navarro (1995). "Vigilance in the greater rhea: effects of vegetation height and group size." Journal of Field Ornithology **66**:215-220.
- Martin, G (1993). Producing the Image. Vision, Brain and Behavior in Birds. H. Zeigler, H-J Bischof. Cambridge, The MIT Press: 16.
- McLean, IG, C Holzer, BJS Studholme (1999). "Teaching predator-recognition to a naïve bird: implications for management." Biological Conservation **87**:123-130.
- Metcalf, N (1984). "The effects of habitat on the vigilance of shorebirds: is visibility important?" Animal Behavior **32**: 981-985.
- Miener, CD, GW Archibald (1996). The cranes: -Status survey and conservation action plan. IUCN. **2002**.
- Mills, A, L Crawford, M Domjan, J Faure (1997). "The Behavior of the Japanese of Domestic Quail *Coturnix japonica*." Neuroscience and Behavioral Reviews **21**: 261-281.
- Mougeot, F, V Bretagnolle (2000). "Predation as a cost of sexual communication in nocturnal seabirds: an experimental approach using acoustic signals." Animal Behavior **60**: 647-656.
- Mueller, H (1975). "Reactions of Quail to Flying Vultures." Condor: 120-121.
- Nagendran, M, R Urbanek, D Ellis (1996). Special Techniques, Part D: Reintroduction Techniques. Cranes, Their Biology, Husbandry, and Conservation. DH Ellis, GF Gee, CM Mirande. Washington, National Biological Service: 231-252.
- Nesbitt, S (2002). Personal Communication - Whooping Crane Mortalities. Florida Department of Wildlife Conservation and Research, Gainesville, Florida.
- Nesbitt, S, MJ Folk (2000). "Reintroduction of the Whooping Crane in Florida." North American Birds **54**: 248.
- Nesbitt, SA (1981). "The Agonistic Repertoire of Sandhill Cranes." Wilson Bulletin **93**: 99-103.
- Noon, BR (1991). "Evidence of continuing worldwide declines in bird populations: insights from an international conference in New Zealand." Conservation Biology **5**: 141-143.

- Norton, TM (1993). Preventative Medicine Protocols for Reintroduction Programs. American Association of Zoo Veterinarians.
- Page, GW, PL Quinn, JC Warriner (1989). "Comparison of the Breeding of Hand- and Wild-Reared Snowy Plovers." Conservation Biology **3**(2): 198-201.
- Pepperberg, IM (2001). "Avian Cognitive Abilities." Bird Behavior **14**: 51-70.
- Pianka, E (1970). "On r & K Selection." American Naturalist **104**: 592-597.
- Powell, AN, FJ Cuthbert (1993). "Augmenting small Populations of Plovers: An Assessment of Cross Fostering and Captive Rearing." Conservation Biology **7**: 160-165.
- Priddel, D, R Wheeler (1994). "Mortality of Captive-raised Malleefowl, *Leipoa ocellata*, released into Mallee remnant within the wheat belt of New South Wales." Wildlife Research **21**: 543-52.
- Priddel, D, R Wheeler (1996). "Effect of age at release on the susceptibility of captive reared Malleefowl *Leipoa ocellata* to predation by the introduced Fox *Vulpes vulpes*." Emu **96**: 32-41.
- Priddel, DRW (1997). "Efficacy of fox control in reducing the mortality of released captive reared Malleefowl *Leipoa ocellata*." Wildlife Research **23**: 469-482.
- Purcell, R (1999). Swift as a Shadow: Extinct and Endangered Animals. New York, Houghton Mifflin. 01.
- Rattenborg, NC, SL Lima, CJ Amlaner (1999). "Facultative control of avian unihemispheric sleep under the risk of predation." Brain Behavioural Research **105**: 163-172.
- Reed, JM (1999). "The Role of Behavior in Recent Avian Extinctions." Conservation Biology **13**: 232-241.
- Robertson, HA, JR Hay, EK Saul, GV McCormack (1994). "Recovery of the Kakerori: An Endangered Forest Bird of the Cook Islands." Conservation Biology **8**: 1078-1086.
- Rovee, CK, LW Kaufman, GH Collier (1977). "Components of predation defense behavior in chickens: evidence for endogenous rhythmicity." Physiology & Behavior **19**: 663-71.

- Sanz, V, A Grajal (1998). "Successful Reintroduction of Captive-Raised Yellow-Shouldered Amazon Parrots on Margarita Island." Conservation Biology **12**: 430-441.
- Sargeant, A, L Eberhardt (1975). "Death Feigning by Ducks in Response to Predation by Red Foxes (*Vulpes fulva*)." The American Midland Naturalist **94**: 109-119.
- Scheuerlein, A, TJ Van't Hof, E Gwinner (2001). "Predators as stressors? Physiological and reproductive consequences of predation risk in tropical stonechats (*Saxicola torquata axillaris*)." Proceedings of the Royal Society of London, B **268**: 1575-1582.
- Seddon, PJ (1999). "Persistence without intervention: assessing success in wildlife reintroductions." Trends in Ecology and Evolution **14**: 503.
- Shedd, DH (1982). "Seasonal variation and function of mobbing and related antipredator behaviors of the american robin (*Turdus migratorius*)." The Auk **99**: 342-346.
- Shettleworth, SJ (2001). "Review: Animal Cognition and Behaviour." Animal Behaviour **61**: 277-286.
- Sinclair, A, R Pech, C Dickman, D Hik, P Mahon, A Newsome (1998). "Predicting effects of predation on conservation of endangered prey." Conservation Biology **12**: 564-575.
- Snyder, N, S Koenig, J Koschmann, H Snyder, T Johnson (1994). "Thick-billed Parrot releases in Arizona." Condor **96**: 845-862.
- Snyder, NF, SR Derrickson, SR Beissinger, JW Wiley, TB Smith, WD Toone , B Miller (1996). "Limitations of Captive Breeding in Endangered Species Recovery." Conservation Biology **10**: 338-348.
- Stahlbaum, CC, C Rovee-Collier, JW Fagen, G Collier (1986). "Twilight activity and antipredator behavior of young fowl housed in artificial or natural light." Physiology & Behavior **36**: 751-758.
- Stephens, PA, WA Sutherland (1999). "Consequences of the Allee effect for behavior, ecology and conservation." Trends in Ecology and Evolution **14**: 401-405.
- Storey, AE, WA Montevecchi, HF Andrews, N Sims (1988). "Constraints on nest site selection: a comparison of predator and flood avoidance in four

- species of marsh-nesting birds (genera: *Catoptrophorus*, *Larus*, *Rallus*, and *Sterna*).” Journal of Comparative Psychology **102**: 14-20.
- Suarez, SD, GD Gallup Jr. (1983). “Emotionality and Fear in Birds a Selected Review.” Bird Behavior **5**: 22-30.
- Sutherland, W (1998). “The importance of behavioral studies in conservation biology.” Animal Behavior **56**: 801-809.
- Swengel, S, G Archibald, D Ellis, D Smith (1996). Behavior Management. Cranes, Their Biology, Husbandry, and Conservation. DH Ellis, GF Gee, CM Mirande. Washington, National Biological Service: 105-122.
- Tacha, T (1981). Behavior and Taxonomy of Sandhill Cranes From Mid-Continental North America. Wildlife and Fisheries Sciences. Oklahoma City, Oklahoma State University: 32-66.
- Thirgood, SJ, SM Redpath, DT Haydon, P Rothery, I Newton, PJ Hudson (2000). “Habitat land and raptor predation: disentangling long- and short-term causes of red grouse declines.” Proceedings of the Royal Society of London, B **267**: 651-656.
- Triggs, SJ, RG Powlesand, CH Daugherty (1989). “Genetic Variation and Conservation of the Kakapo.” Conservation Biology **3**: 92-96.
- Unknown (1993). “Bumper Crop of Chicks at Crane Foundation.” The a.f.a. Watchbird **20**: 48-49.
- Unknown (1999). “Creature Chronicles.” Audubon Institute Quarterly **6**(3): 23.
- Veen, T, DS Richardon, K Blaakmeer, J Komdeur (2000). “Experimental evidence for innate predator recognition in the Seychelles warbler.” Proceedings of the Royal Society of Londond B Biological Sciences **267**: 2253-2258.
- Voss, K (1977). Agonistic Behavior of the Greater Sandhill Crane. Eastern Greater Sandhill Crane Symposium, Michigan City, Indiana: 63-85.
- Voss, KS (1976). Behavior of the Greater Sandhill Crane. Zoology. Madison, Wisconsin-Madison: 144.
- Voss, S (1976). Ontogeny of Behaviour of the Greater Sandhill Crane. International Crane Workshop, Oklahoma State University, Oklahoma State University Publishing and Printing:252-262.

- Vowles, DM, E Prewitt (1971). "Stimulus and response specificity in the habituation of anti-predator behaviour in the ring dove (*Streptopelia risoria*)."
Animal Behaviour **19**: 80-86.
- Wallace, M (1994). "Control of Behavioral Development in the Context of Reintroduction Programs for Birds." Zoo Biology **13**: 491-499.
- Walters, J (1990). "Anti-predator behavior of lapwings: field evidence of discriminative abilities." Willson Bulletin **102**: 49-70.
- Wang, J, N Ryman (2001). "Genetic effects of multiple generations of supportive breeding." Conservation Biology **15**: 1619-1631.
- Wellington, M, A Burke, J Nicolich, K O'Malley (1996). Chick Rearing. Cranes, Their Biology, Husbandry, and Conservation. DH Ellis, GF Gee, CM Mirande. Washington, National Biological Service: 77-104.
- Winkler, DW (1994). "Anti-predator defence by neighbors as a responsive amplifier of parental defence in tree swallows." Animal Behavior **47**: 595-605.
- Wolf, CM, B Griffith, C Reed, SA Temple (1996). "Avian and Mammalian Translocations: Update and Reanalysis of the 1987 survey data." Conservation Biology **10**: 1142-1154.
- Zwank, PJ, CD Wilson (1987). "Survival of Mississippi Sandhill Cranes released on a refuge." Conservation Biology **1**: 165-168.
- Zwank, PJ, JP Geaghan, DA Dewhurst (1988). "Foraging differences between native and released Mississippi Sandhill Cranes: implications for conservation." Conservation Biology **2**: 386-390.

APPENDIX A: Behavior Logs

Table 6: Direct Observation Data Log

Adult Mississippi Sandhill Cranes _____

Date _____ **Time** _____

Predator Used: Bobcat Coyote

Please check off all subadult behaviors observed prior to and during predator exposure (up to 5 minutes) and then 15 minutes thereafter.

Responses should be recorded under observation. A score in the box indicates present, otherwise observation space should be left blank.

Behavior		Observation		
		Pre	Predator	Post
<i>Agonistic</i>	Hiss	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Nonagonistic</i>	Preflight Call	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Guard Call	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Alarm Call	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Unison Call	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Contact Call	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Agonistic</i>	Mobbing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Wing Spread Display	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Crouch	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Run Flap	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Bill Stab/ Bill Sparring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Jump Rake	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Wing Thrash	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Nonagonistic</i>	Alert posture/ Tall alert	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Preflight Posture	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Bunching	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Neck-Stretch-wing-Spread-Run	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Flight	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Table 7. Filmed Observation Data Log

Predator:		Pre								Pred								Post							
Crane ID Date Disk																									
Vocal	Hiss																								
	Contact Call																								
	Preflight Call																								
	Guard Call																								
	Alarm Call																								
	Unison Call																								
Postural	Mobbing																								
	Wingspread Display																								
	Crouch																								
	Run/Flap																								
	Bill Stab																								
	Jump Rake																								
	Wing Thrash																								
	Tall Alert																								
	Preflight Posture																								
	Bunching																								
	Neck Stretch Wing Spread																								
	Run (NSWSR)																								
	Flight																								

Behaviors on denoted on a gray background are agonistic and those listed in a white background are nonagonistic behaviors considered appropriate for use in response to a predator.

APPENDIX B. Tabulated Behaviors of Subadult Mississippi Sandhill Cranes

Table 8. Behaviors of Subadult Mississippi Sandhill Cranes Prior to Exposure to a Coyote.

1 denotes behavior presence in the time of observation (Time Phase); 0 denotes behavior absence.

Crane ID	Age Days	Sex	Treatment	Predator	Time Phase	Guard Call	Contact Call	Tall alert	Pre-flight	NSW SR	Fly	Agonistic
039922	211	F	No Model	Coyote	Prepredator	0	1	0	0	0	0	0
039919	256	M	No Model	Coyote	Prepredator	0	1	0	0	0	0	0
039913	269	M	No Model	Coyote	Prepredator	0	1	0	0	0	0	0
039912	269	M	No Model	Coyote	Prepredator	0	1	0	0	0	0	0
039911	270	F	No Model	Coyote	Prepredator	0	1	0	0	0	0	0
039908	286	F	No Model	Coyote	Prepredator	0	1	0	0	0	0	0
039902	299	F	No Model	Coyote	Prepredator	0	1	0	0	0	0	0
030015	299	F	No Model	Coyote	Prepredator	0	0	0	0	0	0	0
030010	315	F	No Model	Coyote	Prepredator	0	0	0	0	0	0	0
030008	327	F	No Model	Coyote	Prepredator	0	0	1	0	0	0	0
030006	331	F	No Model	Coyote	Prepredator	0	0	0	0	0	0	0
030005	331	M	No Model	Coyote	Prepredator	0	0	1	0	0	0	0
039922	211	F	Model	Coyote	Prepredator	0	1	1	0	0	1	0
039919	256	M	Model	Coyote	Prepredator	0	1	1	0	0	1	0
039913	269	M	Model	Coyote	Prepredator	0	1	1	0	0	1	0
039912	269	M	Model	Coyote	Prepredator	0	1	1	0	0	1	0
039911	270	F	Model	Coyote	Prepredator	0	1	1	0	0	1	0
039908	286	F	Model	Coyote	Prepredator	0	1	1	0	0	1	0
039902	299	F	Model	Coyote	Prepredator	0	1	1	0	0	1	0
030015	299	F	Model	Coyote	Prepredator	0	0	0	0	0	0	0
030010	315	F	Model	Coyote	Prepredator	0	0	0	0	0	0	0
030008	327	F	Model	Coyote	Prepredator	0	0	0	0	0	0	0
030006	331	F	Model	Coyote	Prepredator	0	0	0	0	0	0	0
030005	331	M	Model	Coyote	Prepredator	0	0	0	0	0	0	0

Table 9. Behaviors of Subadult Mississippi Sandhill Cranes During Exposure to a Coyote.

1 denotes behavior presence during in the time phase of observation; 0 denotes behavior absence.

Crane ID	Age Day	Sex	Treatment	Predator	Time Phase	Guard Call	Contact Call	Tall alert	Pre-flight	NSW SR	Fly	Agonistic
039922	211	F	No Model	Coyote	predator	0	0	0	0	0	0	0
039919	256	M	No Model	Coyote	predator	0	0	0	0	0	0	0
039913	269	M	No Model	Coyote	predator	0	0	0	0	0	0	0
039912	269	M	No Model	Coyote	predator	0	0	0	0	0	0	0
039911	270	F	No Model	Coyote	predator	0	0	0	0	0	0	0
039908	286	F	No Model	Coyote	predator	0	0	0	0	0	1	0
039902	299	F	No Model	Coyote	predator	0	1	0	0	0	1	0
030015	299	F	No Model	Coyote	predator	0	1	1	0	1	0	0
030010	315	F	No Model	Coyote	predator	0	0	1	0	1	0	0
030008	327	F	No Model	Coyote	predator	1	1	1	0	1	0	0
030006	331	F	No Model	Coyote	predator	1	0	1	0	0	0	0
030005	331	M	No Model	Coyote	predator	0	0	1	0	0	0	0
039922	211	F	Model	Coyote	predator	0	0	1	0	1	0	0
039919	256	M	Model	Coyote	predator	0	1	1	0	0	0	0
039913	269	M	Model	Coyote	predator	0	1	1	0	0	0	0
039912	269	M	Model	Coyote	predator	0	0	1	0	0	0	0
039911	270	F	Model	Coyote	predator	0	0	1	0	0	0	0
039908	286	F	Model	Coyote	predator	0	1	1	0	0	1	0
039902	299	F	Model	Coyote	predator	0	0	1	0	1	1	0
030015	299	F	Model	Coyote	predator	1	0	1	0	1	0	0
030010	315	F	Model	Coyote	Predator	1	1	1	0	0	0	0
030008	327	F	Model	Coyote	Predator	1	0	1	0	0	0	0
030006	331	F	Model	Coyote	Predator	1	0	1	0	0	0	0
030005	331	M	Model	Coyote	Predator	1	0	1	0	0	0	0

Table 10. Behaviors of Subadult Mississippi Sandhill Cranes After Exposure to a Coyote.

1 denotes behavior presence during the time phase of observation; 0 denotes behavior absence.

Crane ID	Age Day	Sex	Treatment	Predator	Time Phase	Guard Call	Contact Call	Tail alert	Pre-flight	NS WS R	F I y	Agon istic
039922	211	F	No Model	Coyote	Postpredator	0	1	0	0	0	0	0
039919	256	M	No Model	Coyote	Postpredator	0	1	0	0	0	0	0
039913	269	M	No Model	Coyote	Postpredator	0	1	0	0	0	0	0
039912	269	M	No Model	Coyote	Postpredator	0	1	0	0	0	0	0
039911	270	F	No Model	Coyote	Postpredator	0	1	0	0	0	0	0
039908	286	F	No Model	Coyote	Postpredator	0	1	0	0	0	0	0
039902	299	F	No Model	Coyote	Postpredator	0	1	0	0	0	0	0
030015	299	F	No Model	Coyote	Postpredator	1	0	1	0	0	0	0
030010	315	F	No Model	Coyote	Postpredator	1	1	1	1	0	0	0
030008	327	F	No Model	Coyote	Postpredator	1	1	1	0	0	0	0
030006	331	F	No Model	Coyote	Postpredator	1	1	1	0	0	0	0
030005	331	M	No Model	Coyote	Postpredator	1	0	1	1	0	0	0
039922	211	F	Model	Coyote	Postpredator	0	1	1	0	0	0	0
039919	256	M	Model	Coyote	Postpredator	0	1	1	0	0	0	0
039913	269	M	Model	Coyote	Postpredator	0	1	1	0	0	0	0
039912	269	M	Model	Coyote	Postpredator	0	1	1	0	0	0	0
039911	270	F	Model	Coyote	Postpredator	0	1	1	0	0	0	0
039908	286	F	Model	Coyote	Postpredator	0	1	1	0	0	0	0
039902	299	F	Model	Coyote	Postpredator	0	1	0	0	0	0	0
030015	299	F	Model	Coyote	Postpredator	0	0	1	0	0	0	0
030010	315	F	Model	Coyote	Postpredator	0	0	1	0	0	0	0
030008	327	F	Model	Coyote	Postpredator	0	0	1	1	0	0	0
030006	331	F	Model	Coyote	Postpredator	0	1	1	0	0	0	0
030005	331	M	Model	Coyote	Postpredator	0	0	1	0	1	0	0

Table 11. Behaviors of Subadult Mississippi Sandhill Cranes Prior to Exposure to a Bobcat.

1 denotes behavior presence during the time phase of observation; 0 denotes behavior absence.

Crane ID	Age Days	Sex	Treatment	Predator	Time Phase	Guard Call	Contact Call	Tall alert	Preflight	NSW SR	Fly	Agonistic
039922	211	F	No Model	Bobcat	Prepredator							
039919	256	M	No Model	Bobcat	Prepredator							
039913	269	M	No Model	Bobcat	Prepredator							
039912	269	M	No Model	Bobcat	Prepredator							
039911	270	F	No Model	Bobcat	Prepredator							
039908	286	F	No Model	Bobcat	Prepredator							
039902	299	F	No Model	Bobcat	Prepredator							
030015	299	F	No Model	Bobcat	Prepredator	0	0	0	0	0	0	0
030010	315	F	No Model	Bobcat	Prepredator	0	0	0	0	0	0	0
030008	327	F	No Model	Bobcat	Prepredator	0	0	0	0	0	0	0
030006	331	F	No Model	Bobcat	Prepredator	0	1	0	0	0	0	0
030005	331	M	No Model	Bobcat	Prepredator	0	0	0	0	0	0	0
039922	211	F	Model	Bobcat	Prepredator	0	1	1	0	0	0	0
039919	256	M	Model	Bobcat	Prepredator	0	1	1	0	0	0	0
039913	269	M	Model	Bobcat	Prepredator	0	1	1	0	0	0	0
039912	269	M	Model	Bobcat	Prepredator	0	1	1	0	0	0	0
039911	270	F	Model	Bobcat	Prepredator	0	1	1	0	0	0	0
039908	286	F	Model	Bobcat	Prepredator	0	1	1	0	0	0	0
039902	299	F	Model	Bobcat	Prepredator	0	1	1	0	0	0	0
030015	299	F	Model	Bobcat	Prepredator	0	0	1	0	0	0	0
030010	315	F	Model	Bobcat	Prepredator	0	0	1	0	0	0	0
030008	327	F	Model	Bobcat	Prepredator	0	0	1	0	0	0	0
030006	331	F	Model	Bobcat	Prepredator	0	0	0	0	0	0	0
030005	331	M	Model	Bobcat	Prepredator	0	0	1	0	0	0	0

Table 12. Behaviors of Subadult Mississippi Sandhill Cranes During Exposure to a Bobcat.

1 denotes behavior presence during the time phase of observation; 0 denotes behavior absence.

Crane ID	Age Days	Sex	Treatment	Predator	Time Phase	Guard Call	Contact Call	Tail alert	Pre-flight	NSW SR	Flight	Agonistic
039922	211	F	No Model	Bobcat	Predator							
039919	256	M	No Model	Bobcat	Predator							
039913	269	M	No Model	Bobcat	Predator							
039912	269	M	No Model	Bobcat	Predator							
039911	270	F	No Model	Bobcat	Predator							
039908	286	F	No Model	Bobcat	Predator							
039902	299	F	No Model	Bobcat	Predator							
030015	299	F	No Model	Bobcat	Predator	0	0	1	0	0	1	0
030010	315	F	No Model	Bobcat	Predator	0	0	1	0	0	0	0
030008	327	F	No Model	Bobcat	Predator	0	0	0	0	0	1	0
030006	331	F	No Model	Bobcat	Predator	0	0	0	0	0	1	0
030005	331	M	No Model	Bobcat	Predator	0	0	0	0	0	0	0
039922	211	F	Model	Bobcat	Predator	0	1	1	0	0	0	0
039919	256	M	Model	Bobcat	Predator	0	1	1	0	0	0	0
039913	269	M	Model	Bobcat	Predator	0	1	1	0	0	0	0
039912	269	M	Model	Bobcat	Predator	0	1	1	0	0	0	0
039911	270	F	Model	Bobcat	Predator	0	1	1	0	0	0	0
039908	286	F	Model	Bobcat	Predator	0	1	1	0	0	0	0
039902	299	F	Model	Bobcat	Predator	0	1	1	0	0	0	0
030015	299	F	Model	Bobcat	Predator	0	0	1	0	0	0	0
030010	315	F	Model	Bobcat	Predator	1	0	1	0	0	0	0
030008	327	F	Model	Bobcat	Predator	1	0	1	0	0	0	0
030006	331	F	Model	Bobcat	Predator	1	0	0	0	0	0	0
030005	331	M	Model	Bobcat	Predator	1	0	1	0	0	0	0

Table 13. Behaviors of Subadult Mississippi Sandhill Cranes After Exposure to a Bobcat.

1 denotes behavior presence during the time phase of observation; 0 denotes behavior absence.

Crane ID	Age Days	Sex	Treatment	Predator	Time Phase	Guard Call	Contact Call	Tail alert	Pre-flight	NSW SR	Flight	Agonistic
039922	211	F	No Model	Bobcat	Postpredator							
039919	256	M	No Model	Bobcat	Postpredator							
039913	269	M	No Model	Bobcat	Postpredator							
039912	269	M	No Model	Bobcat	Postpredator							
039911	270	F	No Model	Bobcat	Postpredator							
039908	286	F	No Model	Bobcat	Postpredator							
039902	299	F	No Model	Bobcat	Postpredator							
030015	299	F	No Model	Bobcat	Postpredator	0	0	1	0	0	0	0
030010	315	F	No Model	Bobcat	Postpredator	0	0	1	0	0	0	0
030008	327	F	No Model	Bobcat	Postpredator	0	0	1	0	0	0	0
030006	331	F	No Model	Bobcat	Postpredator	0	0	0	0	0	0	0
030005	331	M	No Model	Bobcat	Postpredator	0	0	1	0	0	0	0
039922	211	F	Model	Bobcat	Postpredator	0	0	1	0	0	0	1
039919	256	M	Model	Bobcat	Postpredator	0	0	1	0	0	0	0
039913	269	M	Model	Bobcat	Postpredator	0	0	0	0	1	0	0
039912	269	M	Model	Bobcat	Postpredator	0	1	1	0	0	0	0
039911	270	F	Model	Bobcat	Postpredator	0	1	1	0	0	0	0
039908	286	F	Model	Bobcat	Postpredator	0	1	1	0	0	0	0
039902	299	F	Model	Bobcat	Postpredator	0	0	1	0	0	0	0
030015	299	F	Model	Bobcat	Postpredator	0	0	1	0	0	0	0
030010	315	F	Model	Bobcat	Postpredator	1	0	1	0	0	0	1
030008	327	F	Model	Bobcat	Postpredator	0	0	1	0	0	0	1
030006	331	F	Model	Bobcat	Postpredator	0	0	0	0	1	0	0
030005	331	M	Model	Bobcat	Postpredator	0	0	1	0	0	0	1

APPENDIX C. Information of Subadult Mississippi Sandhill Cranes of this Study

Table 14. Signalment, Release, and Mortality Data of Mississippi Sandhill Cranes of this Study

ID	Conception(A/N) Artificial/ Natural	S e x	APC Date	Transfer Age Months/days	Transfer Date	Debrail Date	Release Date	Site	Field ID	Mortality
039901	A	M	Control	7m 24d	6 Dec 99	20 Dec 99	26 Dec 99	9	952	
039905	N	F	Control	7m 2d	6 Dec 99	20 Dec 99	21 Dec 99	9	953	
039906	N	F	Control	7m 1d	6 Dec 99	20 Dec 99	26 Dec 99	9	954	
039915	A	F	Control	6m 4d	6 Dec 99	20 Dec 99	21 Dec 99	9	955	
039918	A	F	Control	5m 28d	6 Dec 99	20 Dec 99	17 Feb 00	9	956	
039902	A	F	1/12-13/00	9m 7d	2 Feb 00	15 Feb 00	17 Feb 00	10	957	Lead Toxicity 11/30/01
039908	A	F	1/12-13/00	8m 20d	2 Feb 00	15 Feb 00	17 Feb 00	10	959	
039911	N	F	1/12-13/00	8m 8d	2 Feb 00	15 Feb 00	17 Feb 00	10	962	
039912	N	F	1/12-13/00	8m 7d	2 Feb 00	15 Feb 00	17 Feb 00	10	960	
039913	N	M	1/12-13/00	8m 7d	2 Feb 00	15 Feb 00	17 Feb 00	10	963	
039919	A	M	1/12-13/00	7m 24d	2 Feb 00	15 Feb 00	17 Feb 00	10	961	
039922	A	F	1/12-13/00	6m 9d	2 Feb 00	15 Feb 00	17 Feb 00	10	958	
030001	N	M	Control	11m 21d	11 Apr 01	1 May 01	6 May	11	051	
030002	N	F	Control	11m 21d	11 Apr 01	1 May 01	3 May	11	052	
030003	N	F	Control	11m 12d	11 Apr 01	1 May 01	6 May	11	053	
030005	A	M	4/4-13/01	11m 2d	11 Apr 01	1 May 01	6 May	11	054	
030006	A	F	4/4-13/01	11m 2d	11 Apr 01	1 May 01	3 May	11	055	
030008	A	F	4/4-13/01	10m 28d	11 Apr 01	1 May 01	6 May	11	056	
030010	A	F	4/4-13/01	10m 16d	11 Apr 01	1 May 01	6 May	11	057	
030015	A	F	4/4-13/01	10m 0d	11 Apr 01	1 May 01	25 April	11	058	Disappeared 5/22/01
030011	N	F	4/4-13/01	1y 4m 30d	24 Oct 01	15 Nov	17 Nov 01	11	1641	
030012	A	M	4/4-13/01	1y 4m 28d	24 Oct 01	15 Nov	17 Nov 01	11	1642	
030013	A	F	4/4-13/01	1y 4m 27d	24 Oct 01	15 Nov	17 Nov 01	11	1643	
030014	A	F	4/4-13/01	1y 4m 27d	24 Oct 01	15 Nov	17 Nov 01	11	1644	
030021	A	F	4/4-13/01	1y 3m 16d	24 Oct 01	15 Nov	17 Nov 01	11	1646	
030022	A	F	4/4-13/01	1y 3m 8d	24 Oct 01	15 Nov	17 Nov 01	11	1647	
030023	A	M	4/4-13/01	1y 3m 5d	24 Oct 01	15 Nov	17 Nov 01	11	1648	

APPENDIX D. Crane Behavior Recorded during Antipredator Conditioning Trials of Captive Mississippi Sandhill Cranes

Video 1. Tall Alert Posture in Subadult Mississippi Sandhill Cranes

Video 2. Preflight Posture in Subadult Mississippi Sandhill Cranes

Video 3. Guard Call in Subadult Mississippi Sandhill Cranes

Video 4. Bill Stab in Subadult Mississippi Sandhill Cranes

Video 5. Unison Call in Adult Mississippi Sandhill Cranes

VITA

Jennifer Jill Heatley was born to Rita Young and Michael Day Heatley on the 22nd of December 1970, in Dallas, Texas. She graduated from Azle High School in Azle, Texas, 3rd in her class with honors in the spring of 1989. Multiple scholarships made it possible for her to attend Texas A&M University as an applied sciences, wildlife and fisheries science major. She was admitted to the College of Veterinary Medicine of Texas A&M University in the fall of 1991 and was awarded her Doctor of Veterinary Medicine degree in May of 1995. She practiced predominantly small animal and emergency medicine in the private sector from 1995 until 1998. In the fall of 1998 she accepted the position of Wildlife, Zoo, and Exotic Animal Medicine Intern at Louisiana State University in a cooperative agreement with the Baton Rouge Zoo and the Audubon Institute which she successfully completed in the summer of 1999. She is in the process of completing a Wildlife, Zoo and Exotic Animal Medicine Residency at Louisiana State University in cooperative agreement with the Baton Rouge Zoo, and is pursuing eligibility for the American Board of Veterinary Practitioners specialty, avian emphasis. She will receive the degree of Master of Science at the May 2002 commencement.